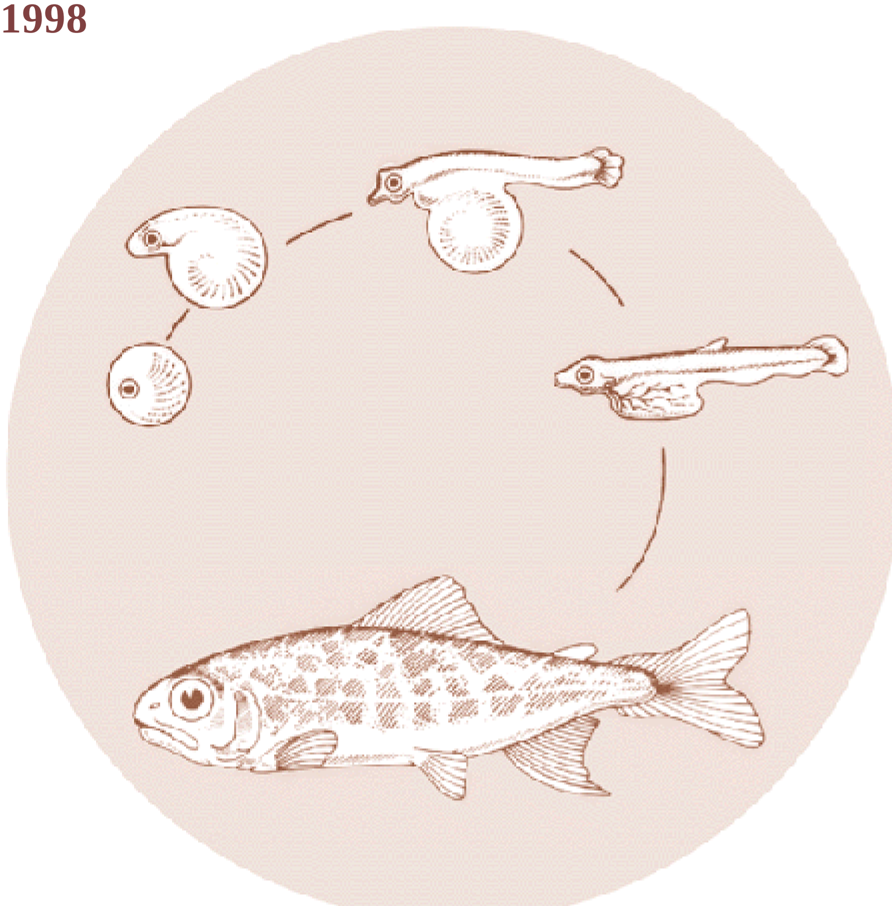
Feasibility for Reintroducing Sockeye and Coho Salmon in the Grande Ronde Basin

Final Report
1998



DOE/BP-30423-1

July 1998

This Document should be cited as follows:

Cramer, Steven, Kenneth Witty, ''Feasibility for Reintroducing Sockeye and Coho Salmon in the Grande Ronde Basin'', Project No. 1988-05301, 171 electronic pages, (BPA Report DOE/BP-30423-1)

Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

THE FEASIBILITY FOR REINTRODUCING SOCKEYE AND COHO SALMON IN THE GRANDE RONDE BASIN

Prepared by:

Steven P. Cramer
Kenneth L. Witty

S.P Cramer & Associates, Inc.

Under Contract to:

Nez Perce Tribal Executive Committee
Nez Perce Fisheries Resource Management

Prepared for:

U.S. Department of Energy
Bonneville Power Administration
Environment, Fish and Wildlife
P.O. Box 3621
Portland, Oregon 97208-3621

Project Number 88-053-01
Contract Number 97AM30423

July 1998

THE FEASIBILITY FOR REINTRODUCING SOCKEYE AND COHO SALMON IN THE GRANDE RONDE BASIN

July 1998

Under Contract to:

Nez Perce Tribal Executive Committee

and

Nez Perce Fisheries Resource Management

Prepared by

Steven P. Cramer

and

Kenneth L. Witty

S.P. Cramer & Associates, Inc.
300 S.E. Arrow Creek Lane
Gresham, OR 97080
(503) 669-0133
www.spcramer.com

ACKNOWLEDGMENTS

A large portion of the data analyzed and presented in this report were obtained from the Enterprise District of ODFW. We are especially thankful to Bill Knox of ODFW for his numerous hours of searching through agency files and reports to extract information for this study. Bill provided valuable insight into the fish populations and habitat of Wallowa Lake and the Grande Ronde Basin.

The search through historical literature and reports for this project was performed by Chadwick Jay, of my staff. Chad wrote the chronology of events presented in Appendix 2, and helped write the section on history of Wallowa Lake sockeye.

Bruce Eddy, ODFW, provided comments to the draft report "Feasibility for Reintroducing Sockeye and Coho Salmon to the Grande Ronde Basin. Many of his comments were incorporated into this report, but some comments were not addressed because be believe that they are more appropriately addressed in Master Plans being developed for sockeye and coho re-introductions in the Grande Ronde River basin.

EXECUTIVE SUMMARY - 1

THE FEASIBILITY OF REINTRODUCING SOCKEYE SALMON INTO WALLOWA LAKE

We estimate peak production of adult sockeye salmon from Wallowa Lake reached 24,000 to 30,000 fish prior to 1900. The run entered the Grande Ronde River between mid June and mid July, and entered the lake during late July and early August. Fish spawned on the lake shore near the head of the lake and in the inflowing Wallowa River. Spawning of sockeye that were intercepted at hatchery racks across the Grande Ronde River near Troy in 1902 and across the Wallowa River near Minam in 1903 peaked about November 1, but spawning in September was reported above the lake in earlier years. Sockeye were extinct from the lake by 1904, as a result of over harvest, unscreened irrigation diversions, and misguided attempts at fish culture beginning in 1903 at the Wallowa Hatchery located 40 miles downstream of Wallowa Lake.

The native population of kokanee in Wallowa Lake remained abundant and supported a popular sport fishery in the lake. The kokanee population collapsed in 1957-63 as a result of two environmental changes. First, a large portion of the spawning area in 1 mile of the Wallow River entering the lake was destroyed by channelization in 1950 to prevent flooding in the state park. Condition of the spawning areas has since improved. Second, lake trout, which prey on kokanee, were stocked during 1956-61 and supported a popular fishery during 1958-65. Reproduction of lake trout evidently was poor, because they disappeared from the catch by 1967. Kokanee imported from Washington, Montana, and British Columbia were stocked intensively beginning in 1962 and these introductions had reestablished a strong fishery by 1966. No kokanee have been stocked in Wallowa Lake since 1982 and the population has been self-sustaining; however, the gene pool is no longer that of the native stock.

Prospects for reintroducing sockeye are fair, but expensive. Introduced fish must be genetically adapted for the long migration to the lake of 792 mile with an elevation gain of 4,383 ft. Total mortality from passing eight Columbia and Snake River dams is estimated to be 57% for smolts and an additional 22% for returning adults. No ocean harvest is expected, but recent harvest rates in the Columbia River have been in the neighborhood of 25% for sockeye. Prespawning mortality in the Grande Ronde River is expected to be at least 25% in favorable years.

Additionally, several major challenges must be overcome for reintroduction to succeed:

1. Temperatures in the Grande Ronde River by mid July commonly reach levels that can be lethal to salmonids. Introduced sockeye must be genetically adapted for tolerance of high temperatures. Sockeye that

reach the mouth of the Wallowa River by mid July will have a survival advantage over those migrating later.

2. Passage over the 36 ft dam at the lake outlet must be provided and minimum flows for adult migration must be secured in the Wallowa River above Joseph. Irrigation ditches below the lake must be screened.

3. The zooplankton community in Wallowa Lake has recently gone through a process of change, and fish communities may also be changing as a result of the establishment of the opossum shrimp, *Mysis relicta*. The abundance of cladoceran zooplankton (preferred food of sockeye) declined and small numbers of lake trout reappeared in the angler catch during the late 1980's. However, little change has occurred during the past 5 years, and an equilibrium may have been reached.

   A similar sequence of events lead to the collapse of kokanee populations in Priest Lake (Idaho), Lake Tahoe (California), and Flathead Lake (Montana). However, the trends in kokanee and lake trout abundance in Wallowa Lake over the past decade indicate that the balance between these populations differs from that in the other lakes cited.

4. Lake Wenatchee and Lake Osoyoos sockeye stocks are the only viable alternatives for immediate use as donor stocks, but they are from outside the Snake River Basin. These two stocks differ genetically from each other and likely also differed from the Wallowa Lake stock. Experimental releases will be necessary to determine which stock, if either, is most viable for Wallowa Lake. Alternatively, the stock from Redfish Lake may become available in the future, if the plan for their recovery is successful.

Further planning for reintroducing sockeye into Wallowa Lake should begin when a donor stock acceptable to resource co-managers is identified and available.

EXECUTIVE SUMMARY - 2

THE FEASIBILITY OF REINTRODUCING COHO SALMON INTO THE GRANDE RONDE RIVER BASIN

We estimate that production of adult coho from the Grande Ronde Basin exceeded 20,000 fish prior to 1902. First attempts at culturing the native run in 1901 indicate that coho began entering the Grande Ronde River in mid September, and that spawning time was bimodal with peaks about November 1 and December 1. Mean fecundity was about 3,000 eggs/female. The original spawning distribution of coho in the basin is poorly defined, but there are reports that coho spawned in the Wenaha River, Catherine Creek, Minam River, Lostine River, and the Wallowa River along with several of its tributaries. The native coho were eliminated from the Wenaha River by 1904 and from the Wallowa River above Minam by 1908 as a result of misguided attempts to culture the runs. A 14 ft dam across the Wallowa River 3 mile below Minam blocked all coho from 1907 to 1924.

Hatchery coho from unknown sources were planted in the Wallowa River 1924-37, and sightings of coho in the Wallowa Basin during 1940-60 probably resulted from these transplants. Coho from Oxbow Hatchery were introduced to the Wallowa River between 1964-68 and reproduced in declining numbers for two generations before essentially disappearing after 1977. Oxbow coho were introduced in the form of 900 adults in 1964 and 200,000 to 350,000 eggs in 1964-68 planted in an incubation channel constructed on Spring Creek near Enterprise. Mark-recapture studies in 1965-67 indicated smolts from these fish emigrated too late in the spring to reach the Columbia Estuary during mid May to mid June, the typical time of ocean entry for coho. Lower Columbia coho have also been used with poor success as a seed stock for reintroducing coho into the middle Columbia Basin and the Yakima River.

The habitat in which coho would have to survive has been substantially modified since the 1800's. Stream surveys by the U.S. Forest Service indicate pool surface area has been reduced by up to 76% since 1940 in the Grande Ronde Basin above La Grande. Irrigation return water and streamside feed lots in the Wallowa Basin have degraded spawning and rearing habitat. Irrigation withdrawals have reduced streamflows. Coho juveniles and adults must now pass eight dams in the Snake and Columbia Rivers. Adult coho faced average harvest rates of 50-80% in the ocean during the 1970's and 1980's, and another 70% in the Columbia River. These rates have been sharply curtailed in the 1990's to about 15% in the ocean and 35% in the Columbia River.

We examined life history traits of five stocks of coho from the lower Columbia for their similarity to the extinct Grande Ronde stock, and found the early-run coho in the Clackamas River to most closely emulate Grande Ronde stock. The Clackamas stock is naturally self sustaining, the adults pass over three high-head dams, and migration and spawning times is similar to the extinct Grande Ronde stock. We recommend this stock be pursued as the donor source for reintroduction.

Simulation of natural coho production in the Wallowa River indicated that passage mortality and harvest rates under current conditions are too high for natural production to be self-sustaining without supplementation. Therefore, a reintroduction program must include annual supplementation.

We developed a first-cut rough estimate that the present carrying capacity for streams in Wallowa County is 290,000 coho parr. Based on this estimate of carrying capacity, expected stock productivity and expected survival rates during passage of dams, we estimate that stocking of 150,000 smolts annually would be required to provide escapement of hatchery and natural spawners that would seed the habitat to capacity.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

This report presents an analysis of existing data to assess the obstacles that would have to be overcome and the magnitude of adult returns that might be achievable if sockeye or coho salmon were to be re-established in the Grande Ronde Basin. This report is not a plan to re-establish these fish, but rather is a feasibility assessment that resource managers can use to determine if reestablishment plans are worth pursuing. The task of assessing the feasibility of reintroducing salmon that have become extinct from the Grande Ronde basin began first with a thorough review of the historic database to determine the biological characteristics of the extinct runs, and to determine the causes of their demise. We reviewed a variety of reports by state and federal agencies, including biennial and annual reports of Oregon fisheries agencies since the reports were first published (Appendix 1), and reviewed the files of the Oregon Department of Fish and Wildlife regarding the Grande Ronde Basin.

This report is divided first into two parts, the reintroduction of sockeye salmon into Wallowa Lake and the reintroduction of coho salmon into the Grande Ronde basin.

PART 1: GRANDE RONDE RIVER BASIN

HYDROLOGICAL CHARACTERISTICS

GRANDE RONDE RIVER AND TRIBUTARIES

The mainstem Grande Ronde River extends 212 mile from its headwaters in the Blue Mountains in Northeastern Oregon to its confluence with the Snake River in Washington. The Grande Ronde River enters the Snake River at river mile (RM) 168.7 and 493 miles above the mouth of the Columbia River. The Grande Ronde River is located above eight dams, four in the Columbia River and four in the Snake River (Figure 1). Further description of the basin is given by ODFW et al. (1990).

The Grande Ronde is fed by four major tributaries, the Wallowa River, the Minam River and the Wenaha River. Mean monthly flows peak in April-June and the period of lowest flow extends from August through November (Figures 2 and 3), typical of a stream that is fed primarily by snow melt. The annual flow pattern in the Wallowa River is influenced by flow regulation at Wallowa Lake where a dam at the outlet, completed in 1929 to its present height, enables storage of up to 40,000 acre-feet of water. Water is stored in the lake primarily during April and May, thus reducing outflows, and is released during July-September (Figure 4) to augment flow for irrigation.

Irrigation withdrawals during summer are a major influence on minimum streamflow. Water diversion rights for the Grande Ronde River, Catherine Creek and Wallowa River total about 3,000 cfs. About 60% of these water rights are for irrigation. All three areas are over-appropriated so that not all rights can be filled, due to low natural streamflows (ODFW et al. 1990). These water rights may pose a formidable obstacle to restoring habitat required by sockeye and coho salmon.

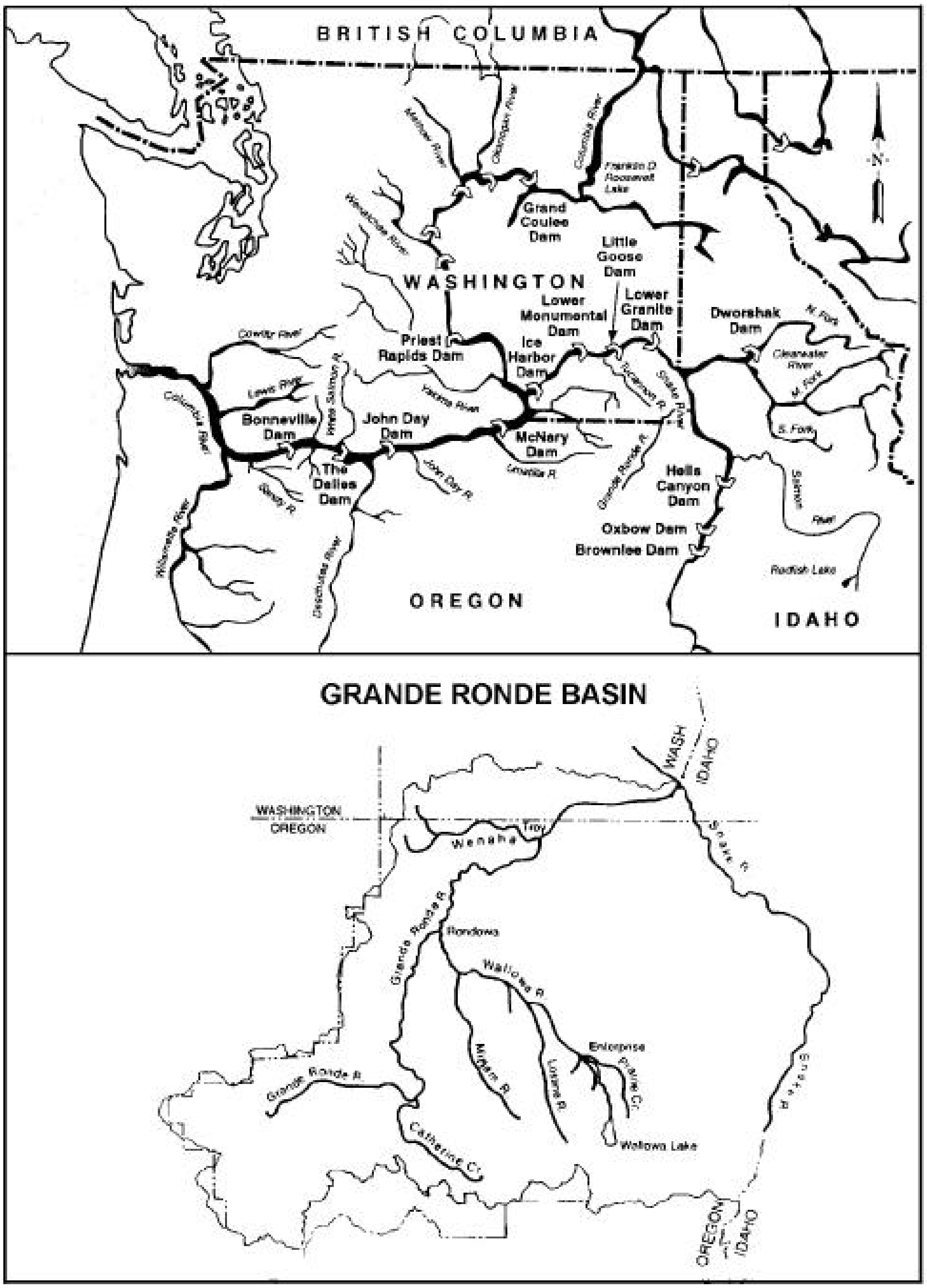
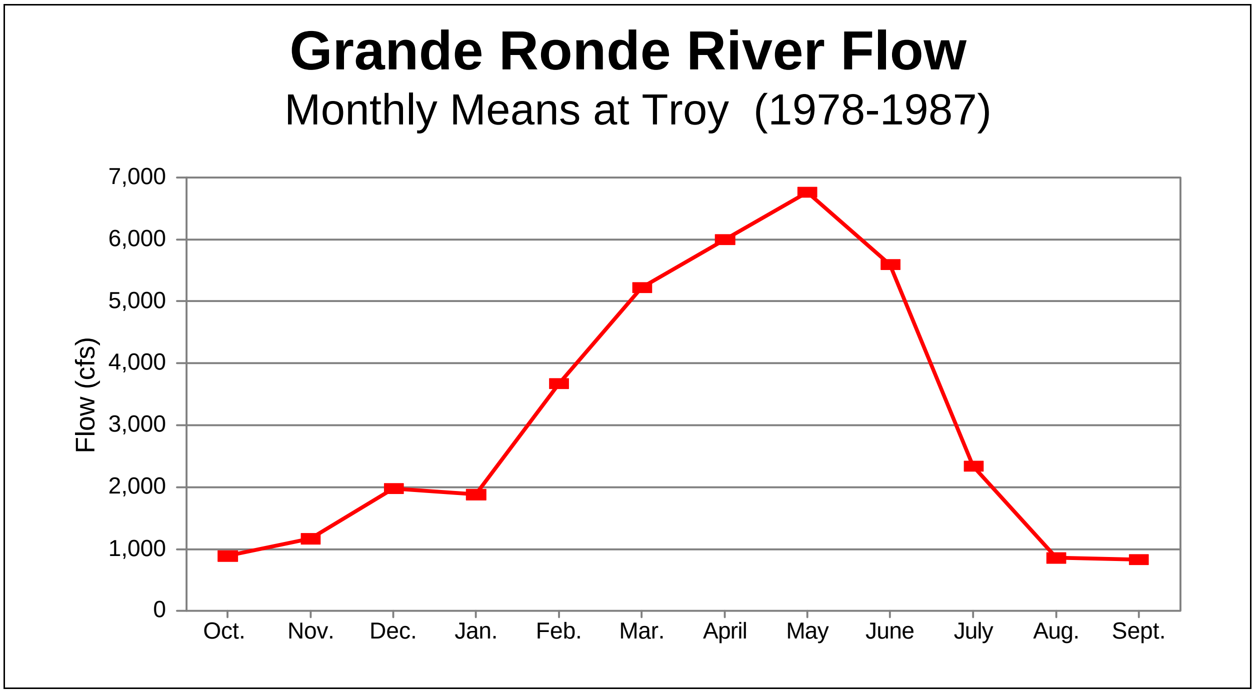


Figure 1. Map of the migration routes for salmon between the ocean and spawning areas in the Grande Ronde River basin.



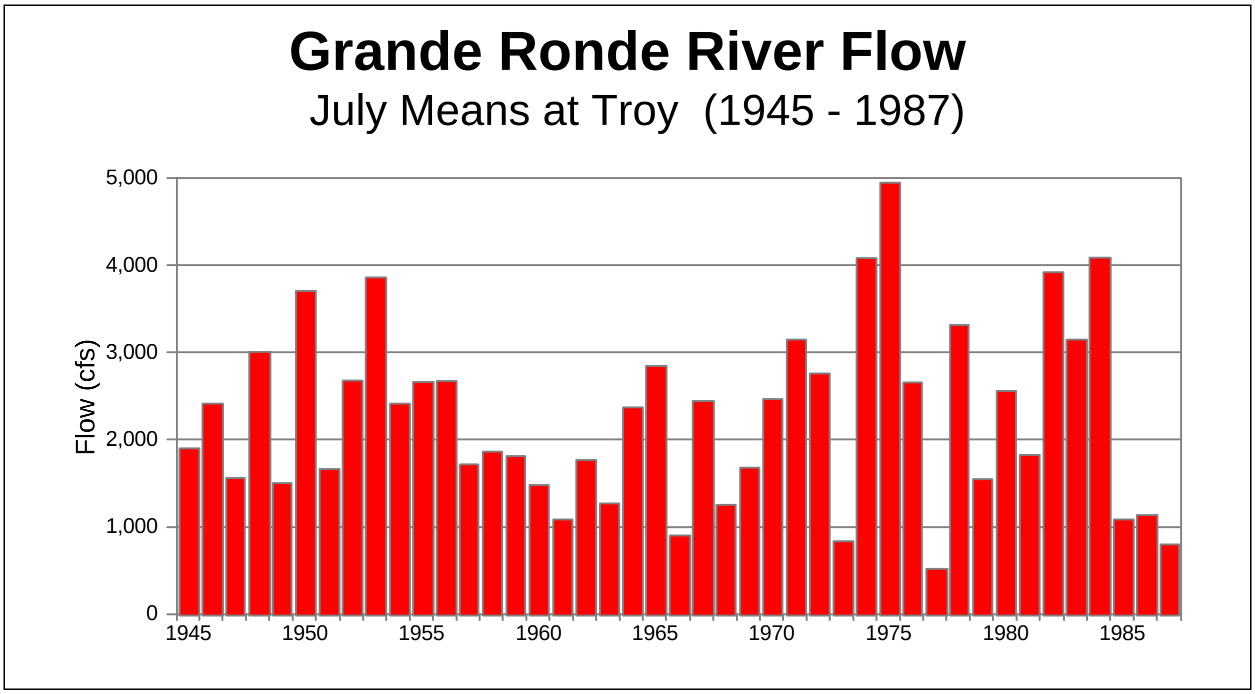
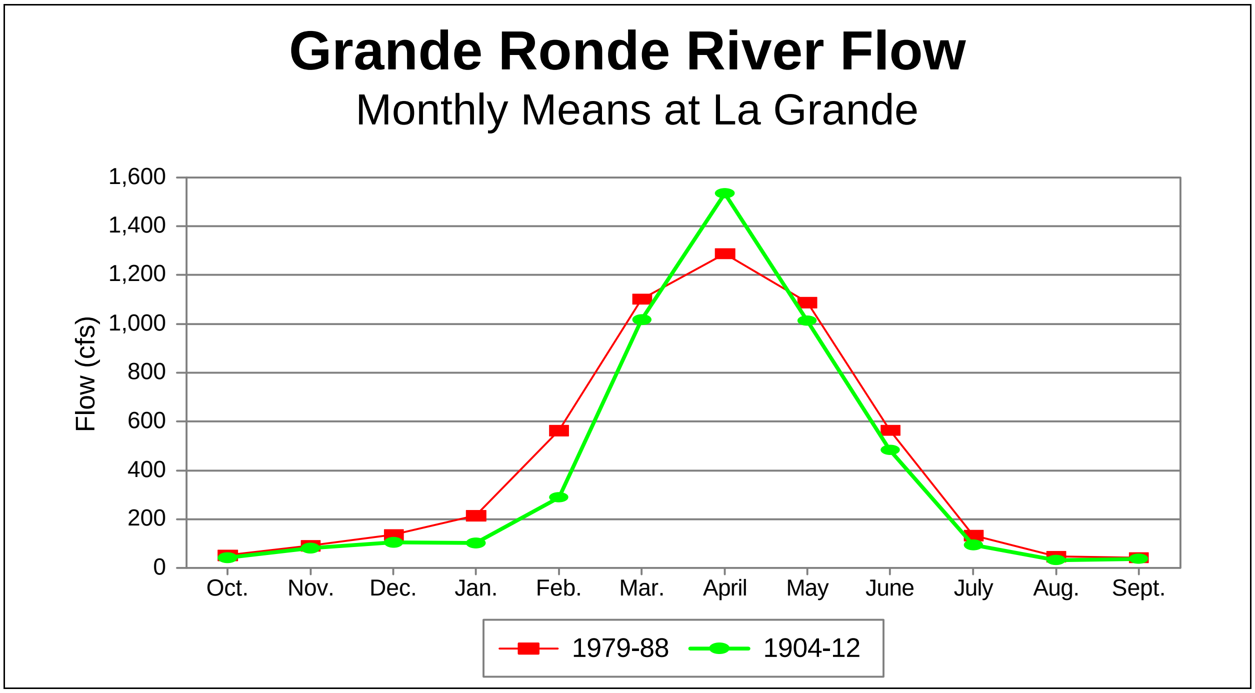


Figure 2. Mean monthly flow (top) of the Grande Ronde River near Troy during 1978-1987 and mean flow during July, 1945-1987 (bottom) (recorded by USGS).



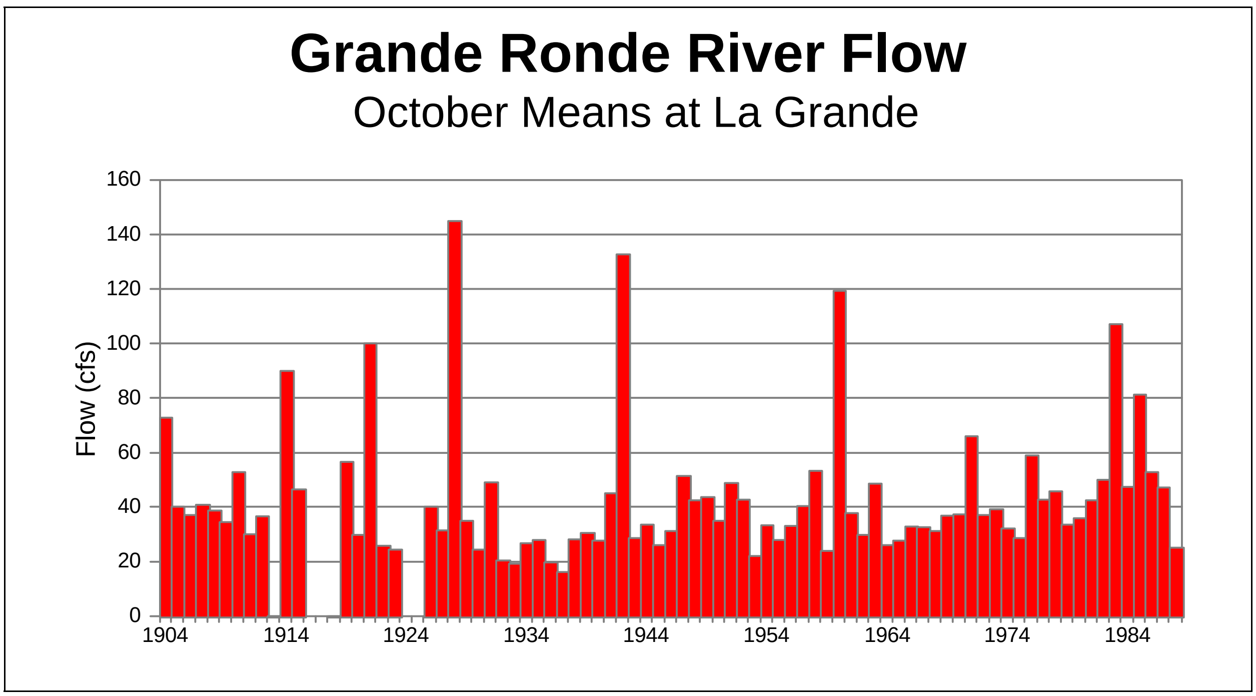


Figure 3. Mean monthly flow (top) of the Grande Ronde River near La Grande and mean flow during October, 1904-1990 (bottom) (recorded by USGS).

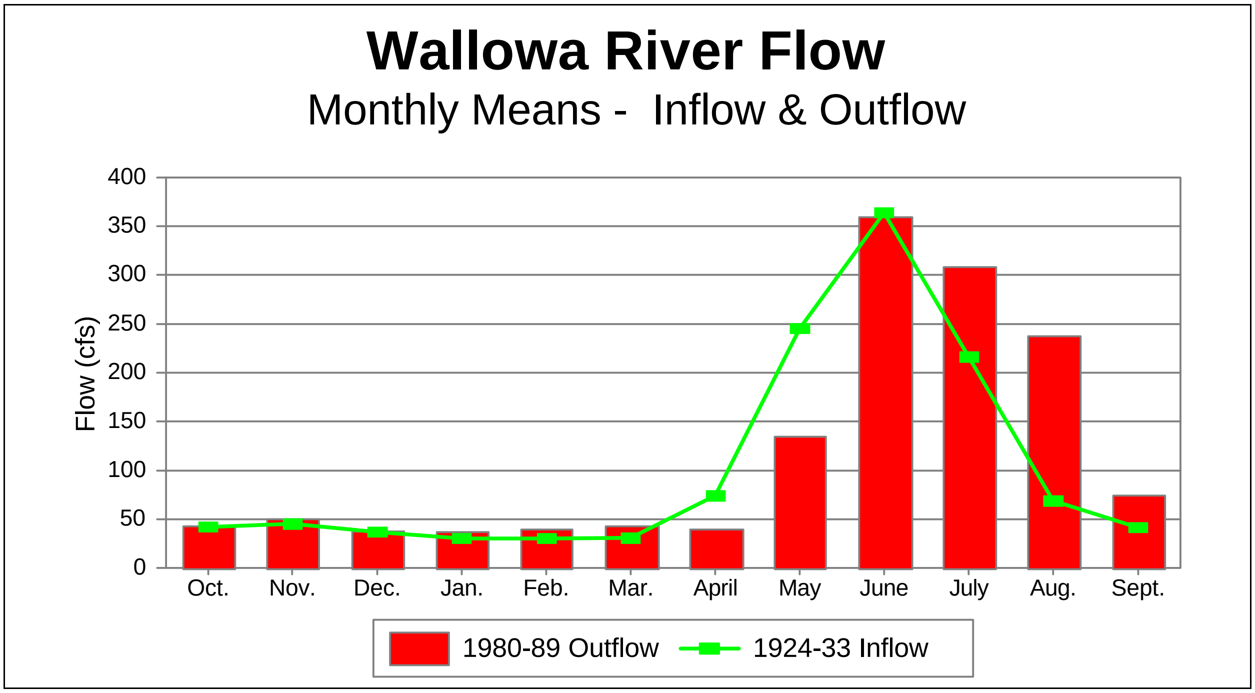


Figure 4. Mean monthly flow of the Wallowa River flowing into Wallowa Lake during 1924-33 and out of Wallowa Lake during 1980-89 (Recorded by USGS).

Water temperature ranges from near freezing in the winter to above lethal levels for salmonids at some times and locations during the summer. Temperature data for the basin have been sparse, but several agencies are now collecting temperature data. Extremes in water temperature are greatest in the upper drainage, as shown by the monthly means recorded at La Grande (RM 158, Figure 5). Mean daily maximums of the river at La Grande exceed 25°C most days during June - August, although daily minimums are near 10°C during the same period. Maximum temperatures in the Wallowa River are less extreme and only occasionally exceed 20°C during summer months (Figure 5). Temperatures of the Grande Ronde at Rondowa (RM 82) typically reach 25°C daily during July and August, but drop to about 10°C each night (Figure 5).

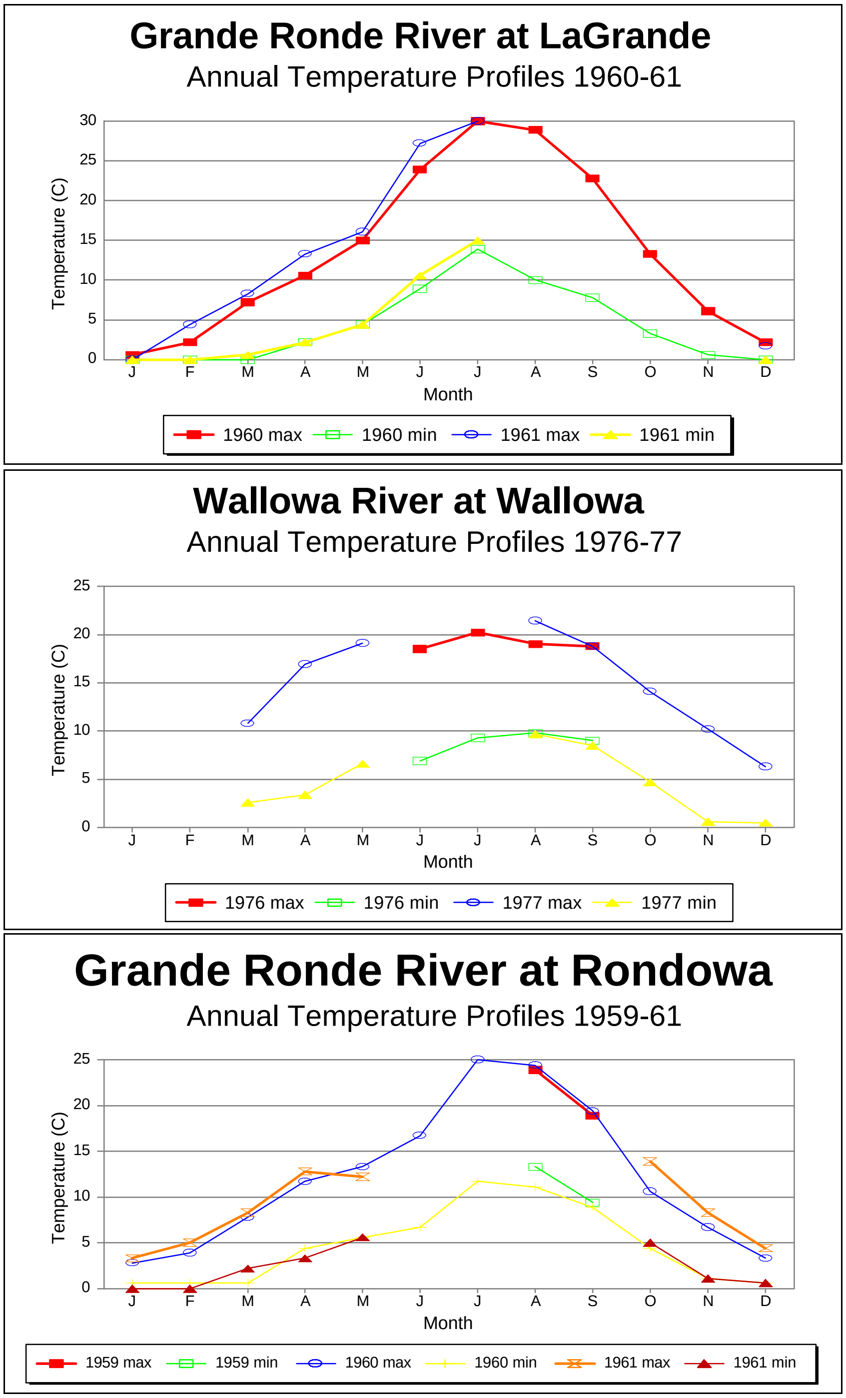


Figure 5. Monthly means of daily minimum and maximum temperatures in the Grande Ronde Basin at three locations (recorded by USGS).

WALLOWA LAKE

Wallowa Lake, at elevation 4,383 ft and 792 river miles from the ocean, lies at the base of the Wallowa Mountains and is a classic example of a glacial moraine lake. The lake was formed by damming of the Wallowa River by two lateral moraines about 900 ft high and a lower terminal moraine at the north end of the lake. The lake is approximately 3.5 miles long and 0.75 miles wide. The cross section of the lake is bowl shaped, with a maximum depth of 299 ft, and only 3% of the lake as littoral zone (Johnson et al. 1965). The lake is fed by the Wallowa River, which branches into a West Fork and East Fork about 1 mile above the lake. The inflowing river has deposited a substantial alluvial plain that has been used by sockeye and kokanee for spawning.

During the summer, the lake develops a distinct thermal stratification with surface waters typically reaching 18°-20°C. Inflow temperatures during summer are usually 7°-8°C cooler than the lake surface (Larson 1973). At depths below 130 ft, the water is perennially near 4°C. Winters are cold and ice frequently forms from a few inches to a few feet thick over the entire lake.

Wallowa Lake is classified as oligotrophic, although the production of phytoplankton is more than expected of a very oligotrophic lake. Total phosphorous is usually low (0.002-0.045 mg/l), turbidity is less than 1 JTU, suspended solids are less than 2 mg/l, and dissolved oxygen is at saturation at all depths (Larson 1981). Transparency (secchi depth) generally ranges from 28 ft to 45 ft. Aquatic plants are nearly absent from the lake.

Water level in Wallowa Lake is regulated by a concrete dam at the outlet that extends 26.8 feet above the natural lake level (Figure 6), thus adding 42,750 acre-ft of storage to the lake (Toner 1960). The outlet for the dam is at the bottom, the sill being 26.8 ft from the crest of the spillway. The outlet consists of six orifices, two of which open to a maximum of 35 inches and empty directly into the Wallowa River. Because of the subsurface outlet, the outflow temperature is generally 3°-6°C cooler than the lake surface waters during July-September (Craig 1967). Water stored in the lake is withdrawn to varying degrees each year for downstream uses, primarily irrigation. The surface level is generally highest in May-June and lowest in September-October (Figure 7).

Figure 6. Photograph of Wallowa Lake Dam (June 1998).

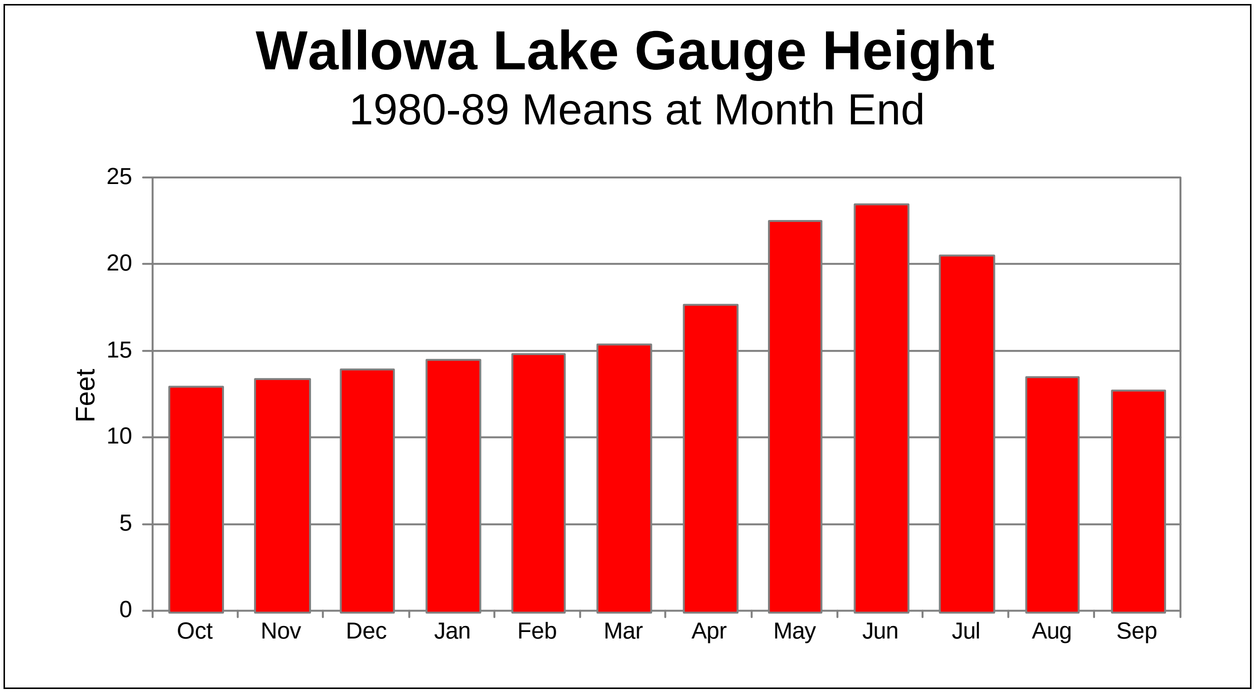
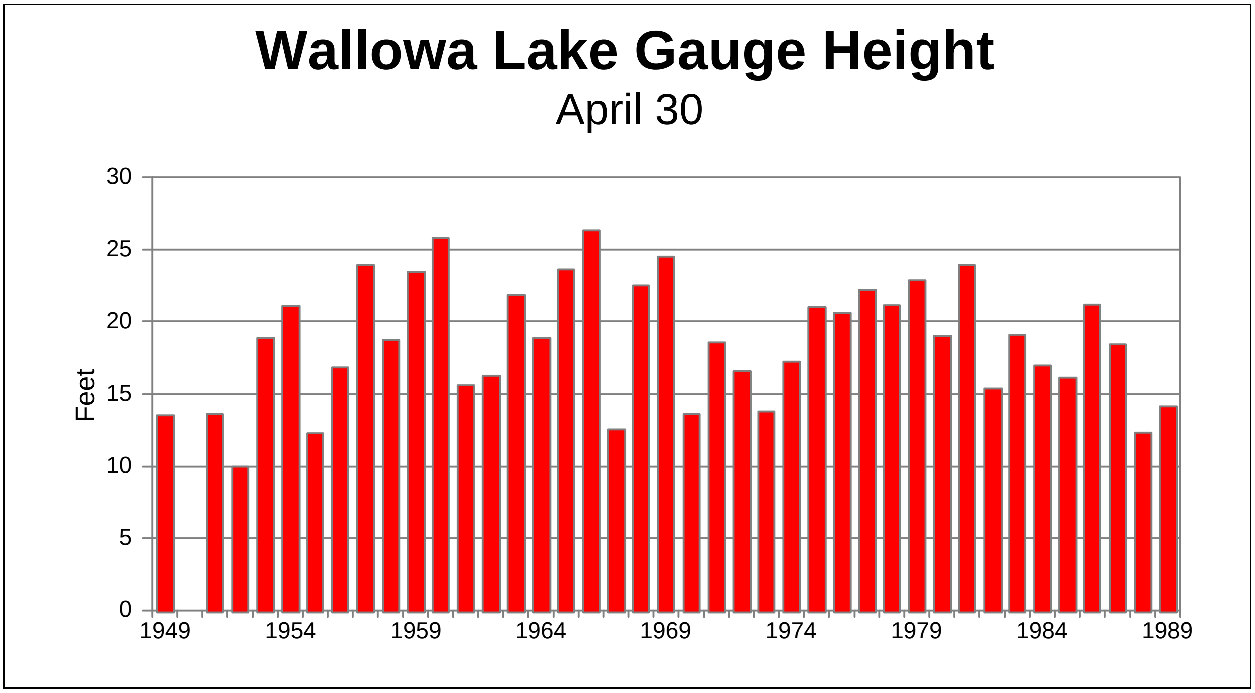


Figure 7. Mean gauge height at Wallowa Lake Dam at the end of each month, 1980-89 (recorded by USGS).

Surface levels vary substantially between years. During April, when sockeye smolts would typically be exiting the lake, the lake level has varied from 10 ft to 27 ft (Figure 8). During July when sockeye adults would typically enter the lake, the lake level has varied from 7 ft to 27 ft (Figure 8). During September and October when kokanee and sockeye typically spawn in the lake, the lake level has varied from 5 ft to 23 ft (Figure 9). Fluctuating lake levels pose a challenge to the operation of fish passage facilities and to lakeshore spawning. These challenges are discussed later in this report.



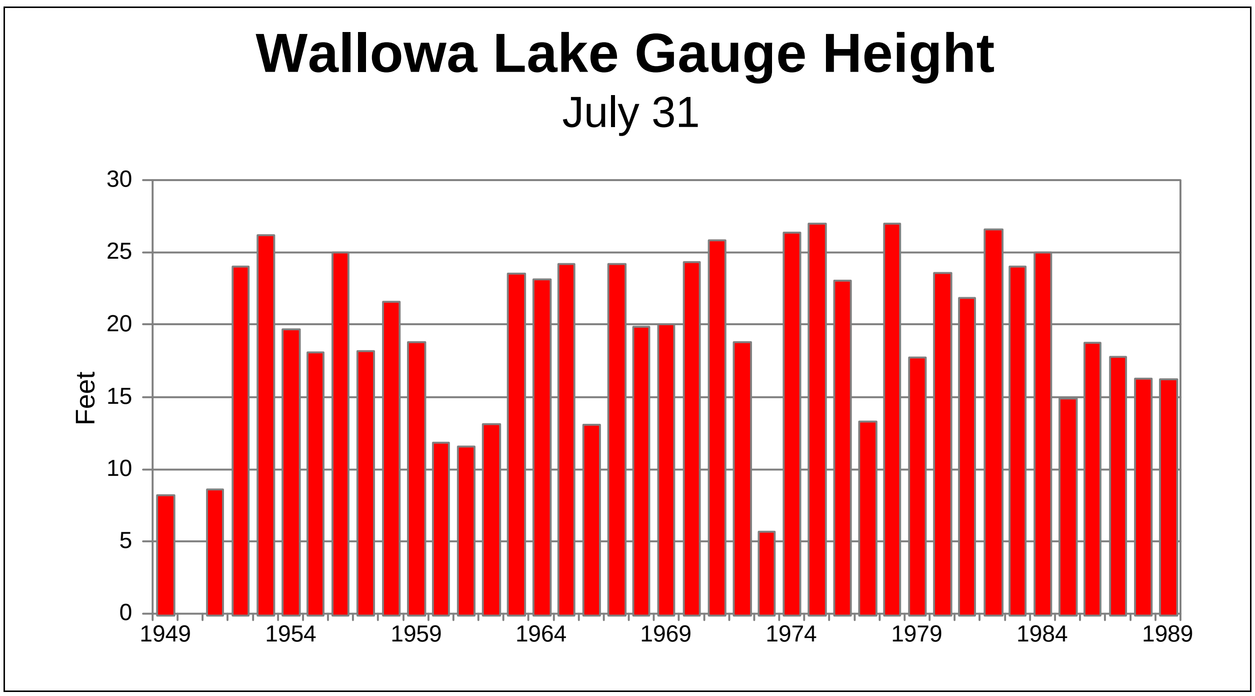
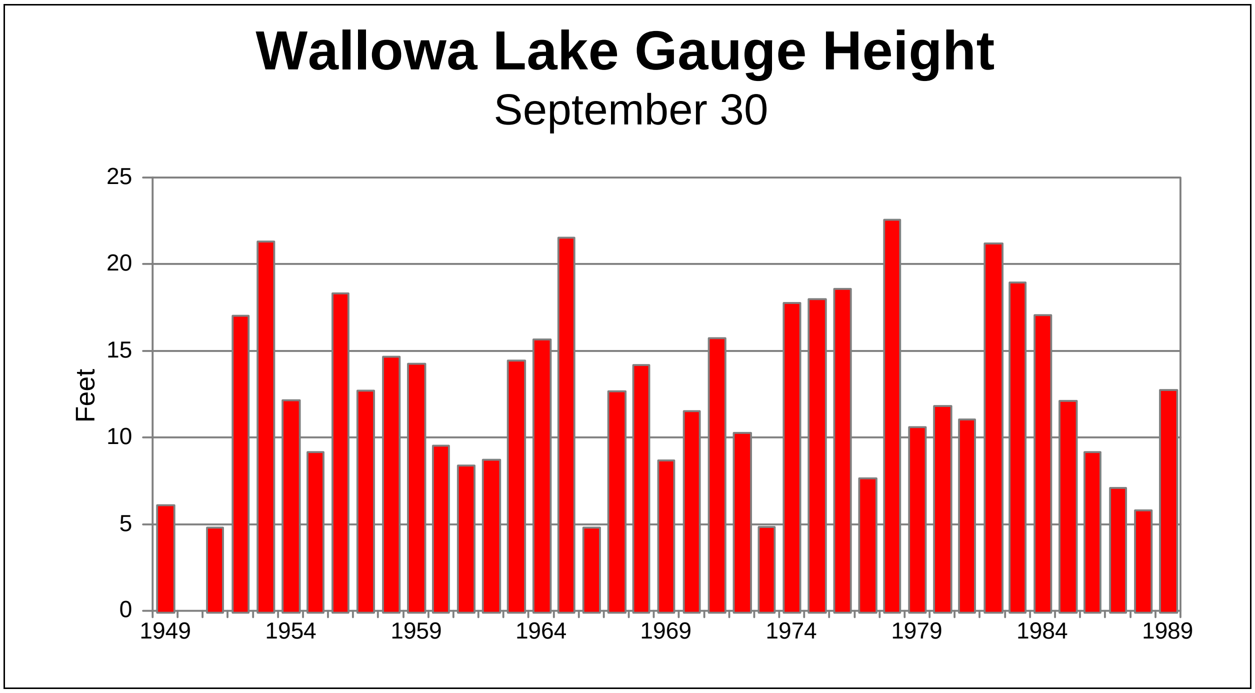


Figure 8. Gauge heights at Wallowa Lake Dam on April 30 and July 31, 1949-89 (Recorded by USGS).



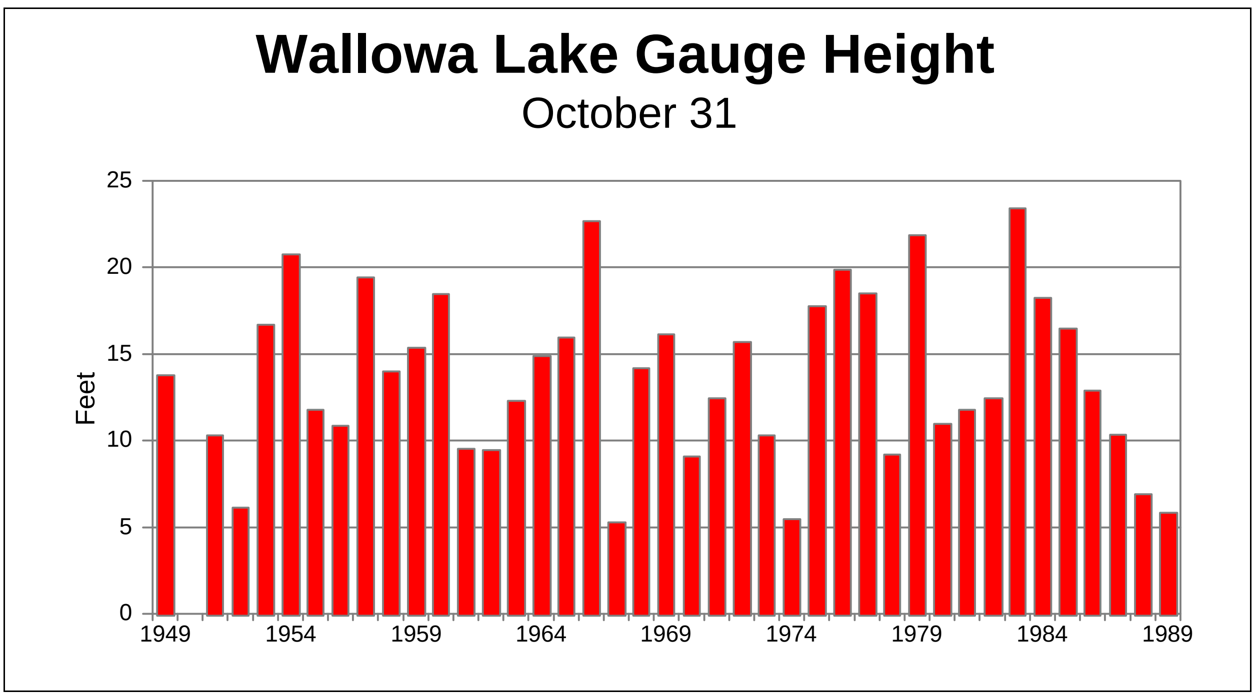


Figure 9. Gauge heights at Wallowa Lake Dam on September 30 and October 31, 1949-89 (recorded by USGS).

THE FEASIBILITY OF REINTRODUCING SOCKEYE SALMON INTO WALLOWA LAKE

BIOLOGICAL BACKGROUND

Sockeye salmon, *Oncorhynchus nerka*, are somewhat unique among pacific salmon in that they are pelagic feeders and the juvenile life history is typically tied to lakes where they rear for one or more years, feeding principally on zooplankton. Smolts migrate to sea in the spring, generally May. Most sockeye spend 2 years at sea before returning to spawn at age 4. Small proportions of the fish return after 1 or 3 years at sea. Adults are small, averaging 4 lb in the Columbia River (ODFW & WDF 1988). Adults migrate upstream in mid summer to their nursery lake and generally hold in the lake for 1-2 months before moving onto the spawning grounds. Adults spawn in inlet and outlet streams and on gravel beaches of the lake where upwelling occurs. Because nearly all fish mature at the same age, cyclic dominance of a cohort is common. The Columbia River is the southern boundary of sockeye distribution.

In addition to the anadromous life history, sockeye commonly exhibit a non anadromous life history of rearing to maturity in lakes. This form is known as kokanee. Most lakes that support sockeye populations also have kokanee populations, but the relative abundance of the two forms varies dramatically between lakes. Kokanee also mature in 4 years where growth is adequate to reach 20-35 cm, but where growth is slow, maturity may be delayed several years.

Life history traits of Wallowa Lake sockeye salmon were never documented, so we can only guess at their life history. It is quite possible that there were two distinct runs of sockeye salmon into Wallowa Lake; one run that spawned in the braided river channels above Wallowa Lake in September and another run that spawned in the lake in spring-fed areas or in the lake outlet in November. Water temperatures are very different between the inlet stream and within the surface waters of the lake, and it is likely that sockeye adapted to these different habitat types. If this were the case, most likely two sockeye salmon stocks with different life history traits existed.

HISTORICAL ABUNDANCE AND DECLINE

Before 1900, sockeye salmon were abundant in Wallowa Lake; although, their numbers varied considerably from year to year (Table 1). A chronology of events from 1875 through 1967 that influenced sockeye and kokanee in Wallowa Lake is listed in Appendix 2. Records of their abundance are annotative, so no precise estimates of the original abundance are available. In 1880, an early settler seined and packed sockeye at the mouth of the river at the head of the lake. Each seine haul contained about 1,500 fish at a reported average weight of 5 lbs (Bartlett 1975). In 1881, about 60,000 pounds of sockeye were caught by two canneries operating on the lake (Bartlett 1975), and in 1894, about 2,000 sockeye were caught at the head of the lake (Evermann and Meek 1897). If the sockeye did weigh an average 5 lbs, then the 60,000 pounds harvested in 1881 represents about 12,000 fish. McGuire (1898) reported that Wallowa sockeye averaged 4.5 lb. However, the average weight of sockeye entering the Columbia River in 1988 was about 4 lbs (ODFW and WDF 1988). If the present day average is more accurate for Wallowa Lake sockeye, then the 60,000 lb harvest in 1881 represents 15,000 fish.

Table 1. Observations of adult sockeye salmon at Wallowa Lake, 1880-1905.

Year	Comments
1880	1,500 fish caught per seine haul at inlet. Unknown total.
1881	Two canneries at inlet. 60,000 lb canned
1882	Two canneries at inlet. 60,000 lb canned
1883	Very large run, no cannery
1884	Less than 100 entered lake
1885	Very small run
1886	Very large run, less than 1883
1887	Very small run
1888	Very small run
1889	Very small run
1890	Very large run
1891	Few fish seen
1892	Few fish seen
1893	Few fish seen
1894	About 2,000 fish caught at inlet
1895	Very small run
1896	Only about 1 dozen seen
1897	Few fish seen
1898	Few fish seen
1899	No fish seen
1900	?
1901	?
1902	2,778 females spawned at Grande Ronde Hatchery near Troy
1903	1,342 females spawned in Wallowa R. Hatchery near Minam
1904	No fish seen, hatchery rack out
1905	Hatchery rack in, but no sockeye return. Run extinct.

In addition to the apparent heavy exploitation of sockeye in Wallowa Lake, harvest rates were also high on migrating sockeye in the Columbia River. Harvest based on cannery pack records ranged from 0.25 to 1.3 million fish during 1889 to 1898 (Figure 10). The cannery pack records show dramatic variation in sockeye abundance between years. The Oregon Fish and Game Protector in his 1898 Annual Report (McGuire 1898) observed,

> "they do not run in abundance every year, the large runs coming every four years and a lesser run every two years. Ten years ago the species was much more abundant in the Columbia than at present. The year 1894 witnessed the largest run of these fish in that stream ever known since the inception of the salmon canning industry."

It is likely that harvest was higher before 1889 when sockeye were first distinguished in the records, because harvest of chinook in the Columbia River peaked in 1883 at 42.8 million pounds, then dropped back to 20 - 30 million pounds per year during 1885 - 1930 (Cleaver 1951). Commercial harvest of salmon in the Columbia River was relatively unrestricted until 1927 when fish wheels were eliminated in Oregon, and in 1935 wheels traps, set nets and seines were eliminated in Washington (Johnson et al. 1948).

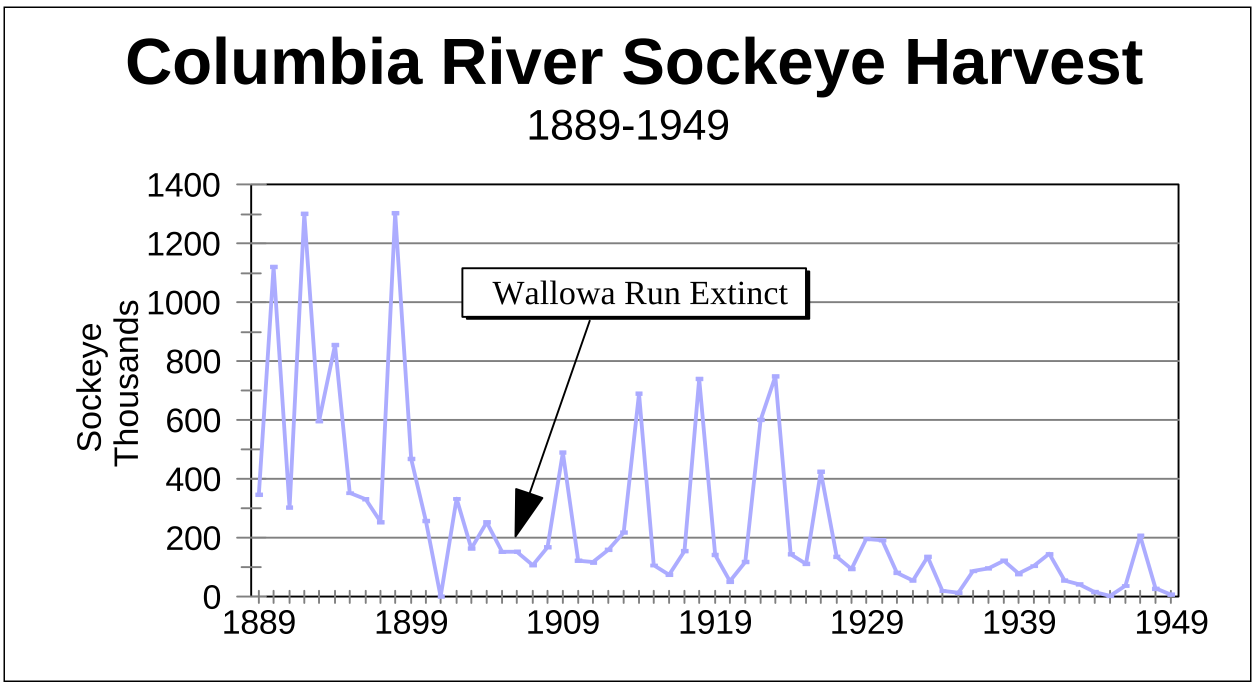


Figure 10. Estimated number of sockeye harvested in the Columbia River each year, 1889-1949. Pounds harvested were obtained from Cleaver (1951) and converted to fish by assuming an average weight of 4.7 lb/fish.

Counts of migrating salmon in the Columbia River were first made in 1933 at Rock Island Dam and began in 1938 at Bonneville Dam. Despite the restrictions that had been placed on commercial harvest, Mullan (1986) estimated the harvest rate on sockeye below Rock Island Dam was 98.4% in 1934 and averaged 84% during 1933-37. Based on counts at Bonneville Dam, the harvest rate of sockeye averaged 69% during 1938-44 (Gangmark and Fulton 1952). Thus, it seems reasonable to assume that sockeye were experiencing at least a 50% harvest rate in the Columbia River in the late 1800's. This would place the 1881 run destined for Wallowa Lake at somewhere between 24,000 to 30,000 fish minimum.

The population of sockeye in Wallowa Lake suffered from losses of smolts into unscreened irrigation diversions, beginning in the 1880's, many of which remained unscreened until the 1960's. These unscreened diversions channeled outward migrating smolts to perish in farm fields. The Fish and Game Protector of Oregon reported in 1898,

> "Farmers and ranchers for years have connected their irrigating ditches with the stream and have failed to erect suitable screens, which has resulted in thousands upon thousands of young fish being carried out upon the open fields to perish," and concluded, "this has nearly exterminated the blueback run of the Columbia River," (McGuire 1898).

The most detrimental and final blow to Wallowa River sockeye, however, appears to have been the attempts by the Oregon Department of Fisheries to culture sockeye. Fish racks were first constructed across the Grande Ronde River near Troy in late August, 1901, but the sockeye run had already passed upstream that year. In 1902, the Grande Ronde was again racked at a point about 2,000 ft above the confluence with the Wenaha River, and 8.65 million sockeye eggs were taken (Reed 1901). The records indicate that 3.654 million eggs were taken from 1,173 females during October, and that another 5 million eggs were taken in November. This additional 5 million eggs would equate to another 1,605 females if fecundity was the same as in October. If the females composed half of the run, then a run of approximately 5,500 sockeye were stopped at the racks in 1902. The report by Reed (1901) also indicates that no fish reached Wallowa Lake that year. Of the eggs taken in 1902, 5 million were planted in a spawning bar below the racks and the other 3.654 million were held to swim up fry and released in the river at the hatchery. This was 86 miles downstream from Wallowa Lake where the sockeye fry would typically rear for at least one year before migrating downstream. In 1903 the rack across the Grande Ronde was abandoned and a new set of racks were placed across the Wallowa River about 1.5 miles below the confluence of the Minam River (about 41 miles downstream from Wallowa Lake). These racks were in the river from July 15 to November 15 and were a complete barrier to fish migration. According to the report of Van Dusen (1905),

> "The result of the work with this variety of salmon shows that 3,901,000 eggs were taken from 1,342 females. No provision was made to take care of these eggs and they were planted as soon as impregnated."

In the light of modern fish culture experience, it is unlikely that any fish survived from the eggs and fry planted in these two years. The hatchery did not operate in 1904 (Van Dusen 1905). In 1905, the hatchery resumed operation; but much to the dismay of hatchery personnel, no sockeye returned to the racks (Van Dusen 1907), and no sockeye were taken through the time the hatchery closed in 1913 (Parkhurst 1950).

Any possibility in the recovery of the Wallowa Lake sockeye run after 1903 (such as the recovery observed in the Columbia River in 1908, Figure 10) was precluded by construction of the Wallowa River Hatchery dam in 1903 and enlarged in 1906 (Figure 11). This dam was 14 feet high and completely blocked passage of fish at a point 3 miles below Minam, 43 miles below Wallowa Lake (McAllister 1909; Riggle 1983). The dam remained until 1924 (Riggle 1983), but was partially destroyed in 1913. After 1913, some fish were apparently able to pass the dam, because sightings of salmon were reported in the Enterprise Record Chieftan July 31, 1919. However, the dam was apparently at least a partial barrier to fish migration because fishermen donated money to have the dam blown out in 1924 (Riggle 1983).

Figure 11. Photograph of Wallowa Hatchery Dam across the Wallowa River near Minam in 1907 (reproduced by permission from Riggle [1983]).

Furthermore, in 1908, officials became concerned over the loss of fish from Wallowa Lake; and since the life history of sockeye salmon was not understood, a screen was constructed over the lake's outflow to keep the salmon from leaving the lake (Bartlett 1975). Spacing of bars in the stationary screen would have allowed passage of small fish the size of sockeye smolts.

Reestablishment of sockeye in Wallowa Lake has been prevented by an 18 ft concrete dam constructed at the lake outlet in 1916. The dam was raised to its present height of 26.8 ft in 1929 (Toner 1960).

Local residents reported sightings of sockeye in Wallowa River between 1917 and 1920 (Toner 1960). However, whether these sightings were truly sockeye salmon might be questioned in light of confusion over the identification of salmon as exemplified by the local newspaper, which in 1919, mentioned a three-foot salmon that was assumed to be a blueback (Enterprise Record Chieftan, July 31, 1919). A typical 4-year-old Columbia River sockeye is about 20 inches long (Mullan 1986).

Most runs of sockeye in the Columbia Basin are now extinct, because dams have blocked access to 96% of the lake surface rearing areas (Mullan 1986). However, substantial populations are still sustaining themselves above seven dams in Lake Wenatchee and above nine dams in Lake Osoyoos. Escapement for both lakes combined exceeded 100,000 fish as recently as 1984 and 1985 (ODFW & WDF 1988). Commercial harvest of sockeye in the Columbia River was closed during 1974-1982 to allow stock rebuilding, and harvest was reinitiated in 1984. Escapement of sockeye to Lake Wenatchee Lake was sufficient to support an excellent sport fishery in the lake during August in 1990 (personal communication with Larry LaVoy, Washington Department of Fisheries, Wenatchee).

POPULATION CHARACTERISTICS

Spawning records from Grande Ronde River Hatchery near Troy during 1902-03 and from Wallowa River Hatchery near Minam during 1903 provide data on the fecundity and spawning time of Wallowa Lake sockeye. Sockeye spawning peaked about the first week of November (Figure 12) and the average fecundity was about 3,100 eggs/female (Appendix 3).

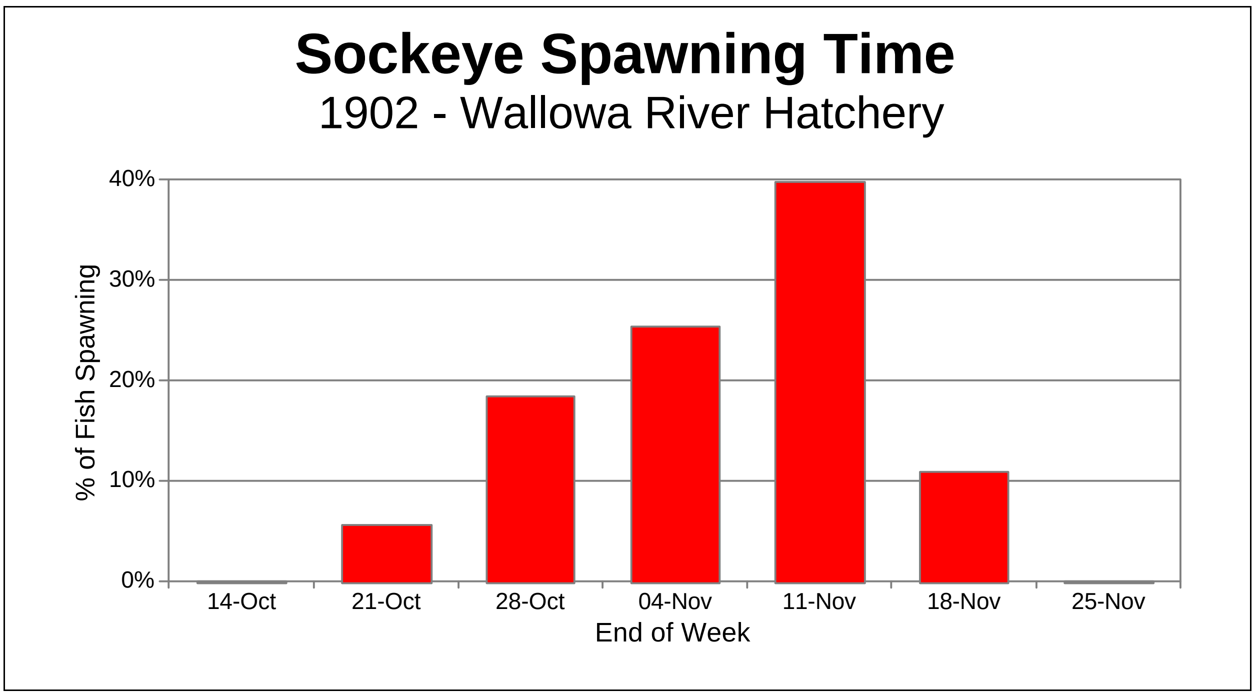


Figure 12. Timing of sockeye spawning at Wallowa River Hatchery in 1902 (data from Van Dusen 1903).

Run timing can be determined from time of arrival at the hatchery racks in 1902 and 1903 and by observed time of entry into Wallowa Lake. Van Dusen (1903) reported that sockeye passed Troy between June 20 and July 20 in 1901. Van Dusen (1905) reported that the first salmon arrived on July 15, 1903 at the racks near Minam. Adult sockeye entered Wallowa Lake in mid-July in silvery condition, with the run lasting about three weeks (Evermann and Meek 1897). Bartlett (1948) also indicates that adult sockeye arrived at Wallowa Lake in July, and that they spawned about 1-2 months later in shallows at the head of the lake and in Indian Creek and the upper Wallowa River. Evermann and Meek (1897) also reported the fish spawned, "in the inlets of the lake and on the shores of its upper end."

Information on the age and length frequency distributions of historic sockeye salmon in the Wallowa River drainage is not available.

Kokanee (non anadromous sockeye) were resident in Wallowa Lake at the same time that anadromous sockeye were abundant. Evermann and Meek (1897) report that "small redfish" or kokanee were seen in schools in September, "at the head of the lake or in the inlets where they spawn, at the same time and on the same beds with the large redfish." Evermann and Meek also report "not more than 1 in 15 is a female; 12 which he caught for us were all males." These fish were sampled by Evermann and Meek during August 19-26, 1896. Further, the immature kokanee, "which he calls "graylings" is usually seen only in June, when it is easily caught by trolling in the lake."

The presence of a large number of males in June suggests that there may have been a large population of precocious male sockeye that did not migrate as smolts. Early angling regulations for Wallowa Lake set liberal bag limits for “yank” which may have been a local name for residual male sockeye. The term “yank” later applied to kokanee harvest regulations at Wallowa Lake.

The population of kokanee persisted in Wallowa Lake after the sockeye run became extinct, but there is no evidence that the population produced anadromous smolts as has been found for Redfish Lake kokanee (Bjornn et al. 1968). Kokanee juveniles with anadromous tendencies would have been heavily selected against for many generations, first because the four main irrigation ditches that divert most of the Wallowa River within 1.5 miles below the lake are unscreened, and second, because any returning adults would have been blocked at the dam near Minam through 1924, and at Wallowa Lake outlet thereafter. Records of catches in irrigation ditch trap boxes during 1948-1988 show no sockeye smolts in the Wallowa River. However, recent sampling with a screw trap in the Wallowa River upstream of Water Canyon Creek has captured a few kokanee displaying anadromous characteristics (Bill Knox, ODFW, personal communication, May, 1998). There have been no confirmed sightings of adult sockeye in the Wallowa River since 1903. We conclude there is no anadromous tendency in the kokanee presently in Wallowa Lake.

HISTORY OF KOKANEE MANAGEMENT IN WALLOWA LAKE

Kokanee have provided a popular sport fishery in Wallowa Lake that has now been monitored for nearly four decades (Table 2). This fishery is presently the most important fishery to Wallowa Lake. Because kokanee are resident sockeye salmon, much can be learned about the potential of Wallowa Lake to produce anadromous sockeye based on the productivity of the kokanee population. Additionally, the influence of density dependence and intra or interspecific competition on growth and survival of sockeye can be inferred from annual variations in growth and survival of kokanee. For this reason, we thoroughly analyzed the historic database on kokanee in Wallowa Lake.

Table 2. Seasonal estimates (by ODFW) of total angler effort and catch in Wallowa Lake, 1954-1990.

			Angler Hours			Angler Catch					
Year	Dates	Days	Total	Boat	Bank	Total	Rainbow	Kokanee	Lake Trout	Dolly Varden	Whitefish
1949	5/1-7/17	78									
1950											
1951	4/28-7/8	71									

			Angler Hours			Angler Catch					
Year	Dates	Days	Total	Boat	Bank	Total	Rainbow	Kokanee	Lake Trout	Dolly Varden	Whitefish
1952	May-Jul	92									
1953	May-Jul	92									
1954	5/2-10/8	160	44,800	27,200	17,600	42,770	39,200	3,145	0	425	
1955	5/1-9/1	124	44,018	28,868	15,150	27,417	23,347	3,695	0	375	
1956	4/28-9/1	127	42,494	26,842	15,652	46,020	32,356	13,190	0	474	
1957									400 a		
1958	4/26-9/3	131	48,236	37,966	10,270	42,862	32,263	9,843	756	0	
1959	not specified	133	33,899	16,855	3,790	30,259	25,770	3,821	504	200	
1960											
1961	not specified	133	19,758			16,501	15,282	934	285	0	
1962											
1963	not specified	102	18,984	18,264	4,827	11,800	10,795	303	654	48	
1964											
1965	4/24-9/15?	145	38,840	26,750	12,090	24,546	19,030	5,190	241	0	85
1966	4/23-10/31	192	57,326	39,562	17,764	41,127	27,797	13,223	45	46	16
1967	4/22-10/31	193	53,399	44,514	8,885	46,277	28,277	18,000	0	0	21
1968	4/20-10/31	195	35,405	26,096	9,309	31,002	14,182	15,198	0	0	29
1969	4/19-10/31	196	31,869	24,274	7,595	32,629	32,307	18,423	0	24	0
1970	4/18-10/31	197	50,810	40,533	10,277	46,328	32,307	14,014	0	0	7
1971	4/24-10/31	191	47,214	35,790	11,424	35,697	28,802	6,895	0	0	0
1972	4/29-10/31	186	44,973	32,757	12,216	45,387	25,520	19,867	0	0	0
1973	5/10-6/30	52	22,385	15,622	6,763	29,797	9,712	20,068	0	0	17
1974	5/9-6/30	53	27,706	22,744	4,962	38,646	7,473	31,136	20	0	17
1975	5/15-7/1	48	22,241	14,781	7,460	26,442	9,165	17,277	0	0	0
1976	4/24-10/31	191	49,684	37,264	8,043	49,803	16,448	32,862	0	482	11
1977	4/23-10/31	192	52,695	29,678	23,017	49,074	23,724	23,394	0	1,903	53
1978	4/22-10/31	193	48,868	31,429	17,439	36,032	23,075	12,280	0	614	63
1979	5/15-6/30	47	22,939	17,609	5,330	33,923	6,016	27,907			
1980	5/15-6/30	47	18,505	14,148	4,357	24,484	5,542	18,942			
1981	5/15-6/30	47	12,764	8,978	3,786	13,887	4,617	9,270			
1982	5/15-6/30	47	23,618	21,242	2,376	37,142	6,519	30,623			
1983	5/15-6/30	47	15,361	13,035	2,326	27,665	6,252	21,413			
1984	5/25-7/15	52	30,303	26,142	4,161	42,646	11,315	31,331			
1985											
1986	5/1-6/29	60	22,920	19,736	3,184		5,544	24,856			
1987	5/1-8/31	123	39,424	34,767	4,657	30,984	8,747	22,215	6	0	16
1988	5/1-8/31	123	39,302	32,530	6,772	33,483	17,982	15,385	19	0	97
1989	5/1-6/30	61	25,466	21,200	4,266	23,454	6,211	17,205	7	0	11
1990	5/1-8/31	123	38,757	29,060	9,697	26,856	14,541	12,285	30	0	?
1991	5/1-6/30	61	18,286	12,954	5,332	18,748	8,835	9,907	3	0	3
1992	5/1-6/30	61	18,875	14,534	4,341	24,627	7,724	16,896	7	0	0
1993	5/1-6/30	61	16,570	10,700	5,870	19,656	9,779	9,873	0	0	4
1994	5/1-6/30	61	18,114	14,763	3,351	20,221	7,223	12,998	0	0	0
1995	5/1-7/21	82	22,940	15,197	7,743	24,341	12,607	11,702	23	0	9
1996	5/13-7/5	53	16,707	11,650	5,057	16,181	5,976	10,179	16	0	10

(a) 29 mackinaw caught in ten days of creel. Proportional expansion to 143 day season gives 415 total catch.

Abundance and Catch

Abundance of kokanee in Wallowa Lake has not been estimated, so variations in abundance must be inferred from catch data. Bowler (1981) found that catch of kokanee per angler hour in several lakes in Idaho was highly correlated to the abundance of harvestable recruits per hectare. We compared harvest and abundance data from Odell Lake, Oregon (Lindsay and Lewis 1975) to Bowler's relationship and found it fit well. However, Bowler's relationship cannot be applied to all situations, because catchability of kokanee is highly influenced by their size (Rieman and Meyers 1990). Mean lengths of spawning kokanee in Odell Lake generally exceed 300 mm (Lindsay and Lewis 1978), but those in Wallowa Lake are generally 200-250 mm (Figure 13). Rieman and Meyers (1990) found that vulnerability was an exponential function of size, with vulnerability dropping to 0 for fish under 180 mm. Further, Rieman and Meyers (1990) showed that growth of kokanee was density dependent, such that at low densities kokanee would grow rapidly and become more vulnerable to harvest than at high fish densities. The resulting combination of density dependent growth and size dependent vulnerability to catch resulted in a theoretical relationship of catch rate to fish density that looks much like that found empirically by Bowler (1981). Thus, harvest and length data combined should provide a good index of abundance and can be used to estimate abundance of catchable sized fish in a lake. We recognize there will be substantial random error in correlation of these variables, because weather at Wallowa Lake during the period of peak kokanee harvest varies year-to-year. Bad weather discourages anglers and catch decreases regardless of fish abundance.

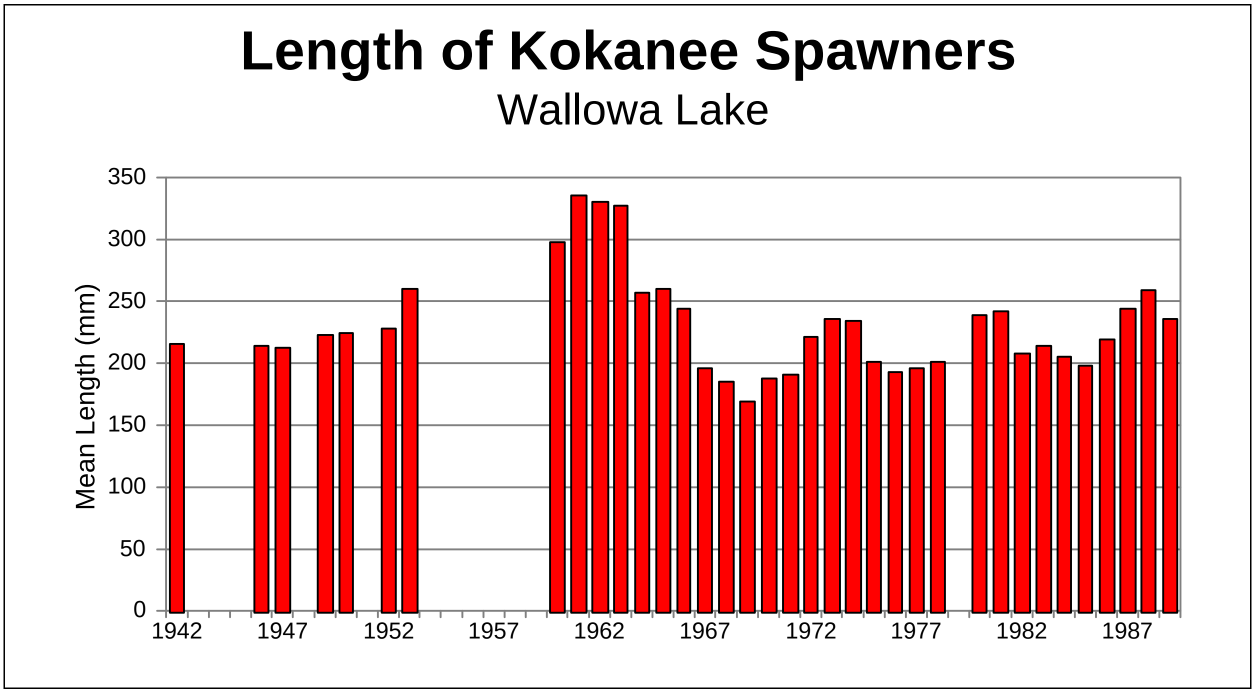


Figure 13. Mean length of kokanee spawners in the Wallowa River in late September, 1942-89 (data from ODFW).

Angler surveys were initiated on Wallowa Lake in 1949, although they were not designed to estimate total harvest until 1954. The period for which harvest was estimated changed from year to year (Table 2), so the estimates of total annual harvest are not directly comparable. Surveys of angler harvest in Wallowa Lake were generally stratified according to the following seasons:

1. April 20 to May 7
2. May 8 to June 30
3. July 1 to September 15
4. September 16 to October 31

Kokanee in Wallowa Lake were harvested predominantly in May-June (Figure 14) and anglers were sampled during this period in nearly every year since 1949, so we used catch and effort in May-June for analysis of annual harvest. Harvest during 1954 to 1963 was estimated for variable season lengths, but was not divided into seasonal strata, so we used the estimates in other years to estimate the proportion of effort and catch that would have occurred in the May-June strata. Not only did catch rate vary between seasonal strata, but angler effort did also (Figure 15). At least three of the four seasonal strata were sampled in each 1965-72 and 1976-78, so we used these years to estimate the proportional relationship between seasonal strata for average angler effort per day and catch per hour. These procedures assume that the true proportion of harvest and effort each year within each of the seasonal strata is constant. The equation we wished to solve was:

Catch = (Kokanee/Angler-hour)*(Angler-hours/day)*(Days)
or
C(s,t) = CPE(s,t) * EPD(s,t) * D(s)

where

C = Catch of kokanee
D = No. days to which estimate applies
EPD = Effort (angler hours) per day
CPE = Catch of kokanee per angler hour
s = seasonal stratum, 1-4
t = type of angler, boat or bank

In order to solve the above equation in years where strata were not differentiated, we proceeded as follows:

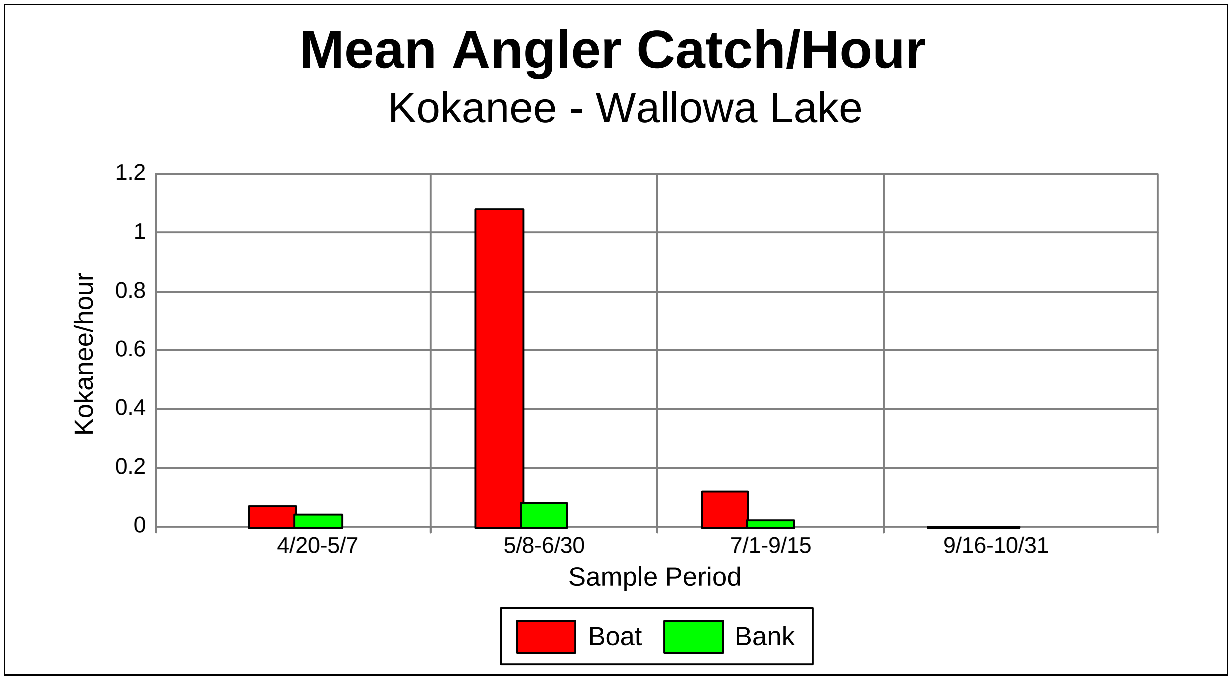
Estimate the effort in each stratum as a proportion of the effort in stratum 2.

EPDratio(s,t) = Σ{[H(s,t,yr)/D(s,t,yr)]/[same for stratum 2]}/n

CPEratio(s,t) = Σ{[C(s,t,yr)/H(s,t,yr)]/[same for stratum 2]}/n

where

n = number of years summed



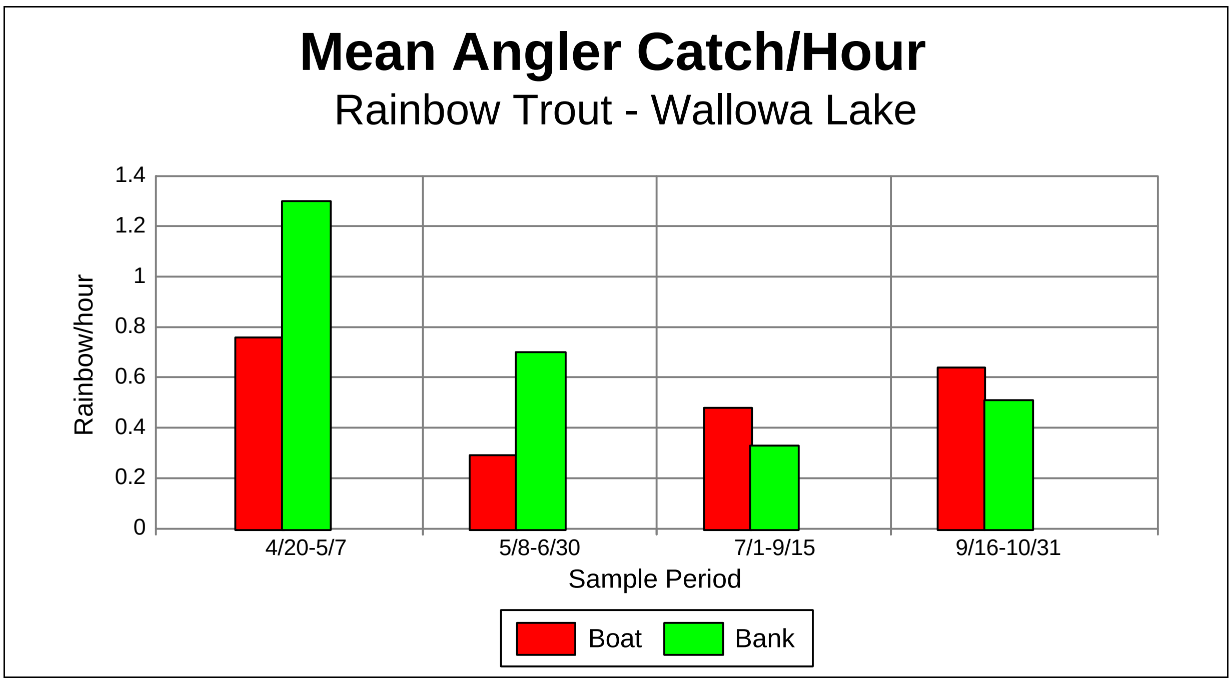


Figure 14. Mean catch of kokanee and rainbow trout per hour by boat and bank anglers at Wallowa Lake for each seasonal stratum used in ODFW angler surveys. Means are averages for 1965-72 and 1976-78, because these were the only years in which at least three strata were sampled.

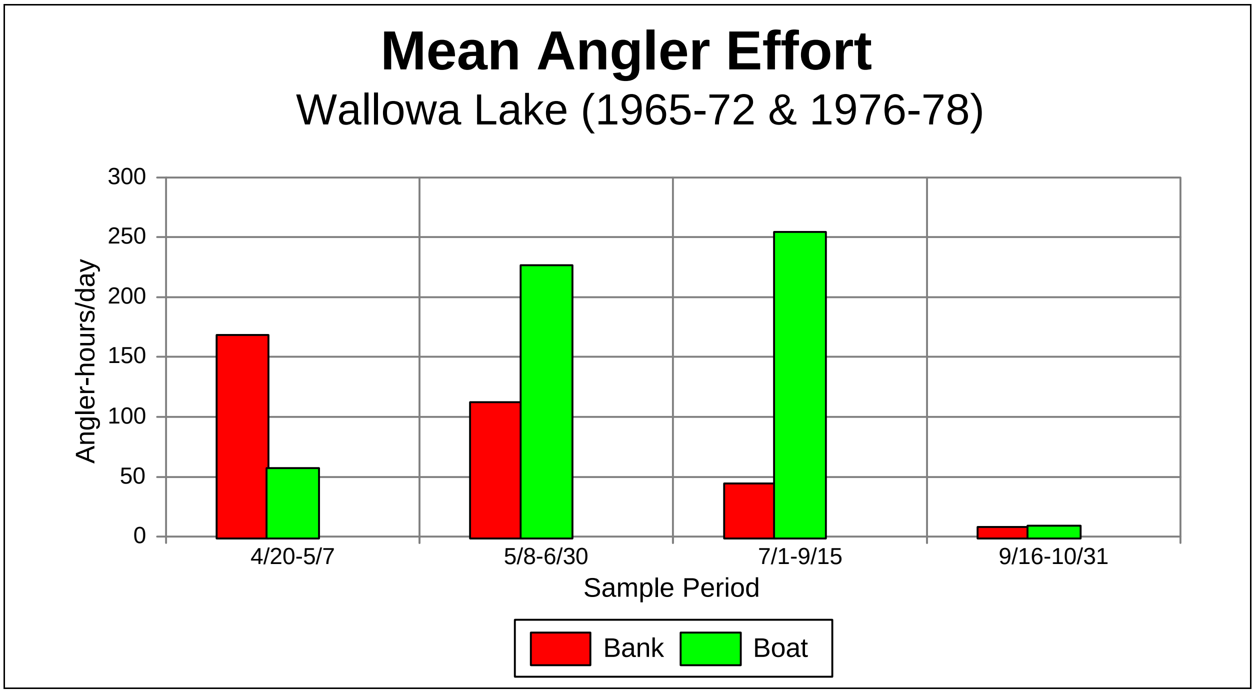


Figure 15. Mean number of angler hours per day at Wallowa Lake during each seasonal stratum used in ODFW angler surveys. Means are averages for 1965-72 and 1976-78 because these were the only years in which at least three strata were sampled.

Calculated means of the EPD ratio and CPE ratio for each stratum are presented in Table 3. Complete data used in these calculations are presented in Appendixes 4-7. Next, we substituted in the known values of total catch and effort and the number of days in each stratum into the following equations:

$$EPD(2,t) = H(\Sigma s,t)/\Sigma[EPDratio(s,t) * D(s,t)]$$

$$CPE(2,t) = C(\Sigma s,t)/\Sigma[D(s) * EPD(s,t,yr) * CPEratio(s,t)]$$

where

H = angler hours
and the summations are over all strata, s.

Estimated catch and effort for the May-June stratum are presented in Table 4.

Catch and catch per hour of kokanee followed similar trends with a few exceptions (Figure 16). The most notable feature of Figure 16 is the apparent collapse of the kokanee population between 1959 and 1964. Although the total harvest of kokanee was not estimated prior to 1954, angler surveys indicated catch rates had been substantially higher during 1949-53 than during 1959-64. Other data also reflect the collapse of the kokanee population in 1959-64. Mean lengths of the few remaining kokanee sampled on the spawning grounds rose sharply (see Figure 13). This density dependent growth response has been demonstrated elsewhere (for a review see Rieman and Meyers 1990). Rieman and Meyers (1990) warn that sharp increases in length at harvest and maturity are warning signals of a declining population. Observations of kokanee spawners in the Wallowa River also show the collapse of the spawning population during 1959-1964 (Table 5).

Table 3. Proportionate angler effort (EPD ratio) and catch rate (CPE ratio) at Wallowa Lake by seasonal stratum expressed as a proportion of the average during the May 8 - June 30 stratum. Values are averages for 1965-72 and 1976-78 from ODFW angler surveys.

	Mean Angler-Hours/day		Boat		Bank	
Period	**Bank**	**Boat**	**Rb/hour**	**Kok/hour**	**Rb/hour**	**Kok/hour**
4/20-5/7	1.67	0.23	1.52	0.06	4.47	0.67
5/8-6/30	1.00	1.00	1.00	1.00	1.00	1.00
7/1-9/15	0.47	1.37	2.45	0.14	0.50	0.34
9/16-10/31	0.09	0.05	2.07	0.00	0.74	0.02

Table 4. Angling effort and catch of rainbow trout and kokanee during May-June at Wallowa Lake, 1949-90 (estimated by ODFW).

	Inclusive	Days in	Angler Hours			Rainbow Caught			Kokanee Caught			Kokanee/
Year	Dates	Stratum	Total	Boat	Bank	Total	Boat	Bank	Total	Boat	Bank	Boat hour
1949	5/1-7/17	78										0.530
1950												0.900
1951	4/28-7/8	72										1.380

Year	Inclusive Dates	Days in Stratum		Angler Hours			Rainbow Caught			Kokanee Caught			Kokanee/ Boat hour
				Total	Boat	Bank	Total	Boat	Bank	Total	Boat	Bank	
1952	May-Jul	92											0.770
1953	May-Jul	92											0.250
1954	5/8-6/30	54	(a)	18,308	8,999	9,309				2,568	2,437	131	0.271
1955	5/8-6/30	54	(a)	19,402	10,984	8,418				3,082	2,810	272	0.256
1956	5/8-6/30	54	(a)	18,747	10,197	8,550				10,939	9,803	1,136	0.961
1957													
1958	5/8-6/30	54	(a)	18,964	13,801	5,163				7,911	6,733	1,178	0.488
1959	5/8-6/30	54	(a)	6,329	4,452	1,877				1,741	1,519	222	0.341
1960													
1961	5/8-6/30	54	(a)	3,020	1,796	1,224				766	703	63	0.391
1962													
1963	5/8-6/30	54	(a)	6,395	1,735	4,660				195	129	66	0.075
1964													
1965	5/7-6/30	55		22,290	14,690	7,600	10,430	4,770	5,660	3,820	3,820	0	0.260
1966	5/7-6/30	55		19,614	12,065	7,549	11,427	4,147	7,280	12,673	12,023	650	0.997
1967	5/8-6/30	54		19,855	15,529	4,326	3,661	889	2,772	17,208	17,050	158	1.098
1968	5/8-6/30	54		12,397	10,050	2,347	5,251	2,904	2,347	10,602	10,450	152	1.040
1969	5/8-6/30	54		10,252	8,450	1,802	2,727	1,956	771	12,805	12,680	125	1.501
1970	5/8-6/30	54		14,021	8,350	5,671	7,969	3,387	4,582	10,605	9,203	1,402	1.102
1971	5/9-6/30	53		10,397	5,420	4,977	5,368	2,350	3,018	4,188	3,868	320	0.714
1972	5/9-6/30	53		20,268	13,940	6,328	8,449	4,077	4,372	18,802	18,424	378	1.322
1973	5/10-6/30	52		22,385	15,622	6,763	9,712	4,099	5,613	20,068	2,037	18,031	0.130
1974	5/9-6/30	53		27,706	22,744	4,962	7,473	5,633	1,840	31,136	30,315	821	1.333
1975	5/15-7/1	48		22,241	14,781	7,460	9,165	3,000	6,165	17,277	16,871	406	1.141
1976	5/9-6/30	53		23,398	16,415	6,983	8,374	2,969	5,405	32,011	30,645	1,366	1.867
1977	5/9-6/30	53		28,647	16,777	11,870	13,072	5,128	7,944	20,702	20,030	672	1.194
1978	5/9-6/30	53		23,290	14,589	8,701	10,069	4,184	5,885	11,505	10,984	521	0.753
1979	5/15-6/30	47		22,939	17,609	5,330	6,016	3,410	2,606	27,907	27,848	59	1.581
1980	5/15-6/30	47		18,505	14,148	4,357	5,542	1,702	3,840	18,942	18,892	50	1.335
1981	5/15-6/30	47		12,764	8,978	3,786	4,617	2,069	2,548	9,270	9,270	0	1.033
1982	5/15-6/30	47		23,618	21,242	2,376	6,519	4,241	2,278	30,623	30,592	31	1.440
1983	5/15-6/30	47		15,361	13,035	2,326	6,252	3,649	2,603	21,413	21,285	128	1.633
1984	5/25-7/15	52		30,303	26,142	4,161	11,315	7,050	4,265	31,331	31,195	136	1.193
1985													
1986	5/1-6/29	60		22,920	19,736	3,184	5,544	3,769	1,775	24,856	24,828	28	1.258
1987	5/1-6/30	61		22,960	21,167	1,793	1,016	643	373	21,687	21,687	0	1.025
1988	5/1-6/30	61		18,922	15,664	3,258	5,989	2,812	3,177	14,495	14,488	7	0.925
1989	5/1-6/30	61		25,466	21,200	4,266	6,211	3,334	2,877	17,225	17,198	27	0.811
1990	5/1-6/30	61		18,645	13,632	5,013	6,494	2,590	3,904	10,777	10,742	35	0.788
1991	5/1-6/30	61		18,286	12,954	5,332	8,835	2,762	6,073	9,907	9,884	23	0.763
1992	5/1-6/30	61		18,875	14,534	4,341	7,724	2,579	5,145	16,896	16,743	153	1.152
1993	5/1-6/30	61		16,570	10,700	5,870	9,779	4,472	5,307	9,873	9,864	9	0.922
1994	5/1-6/30	61		18,114	14,763	3,351	7,223	4,150	3,073	12,998	12,998	0	0.880
1995	5/1-6/30	61		14,676	9,540	5,136	7,879	2,614	5,265	9,009	8,953	56	0.939
1996	5/13-7/5	53		16,707	11,650	5,057	5,967	2,882	3,094	10,179	10,143	36	0.871

(a) Estimated from single value reported for season. See text for explanation.

(b) Includes bank catch and effort, so catch/hour is underestimated for boats.

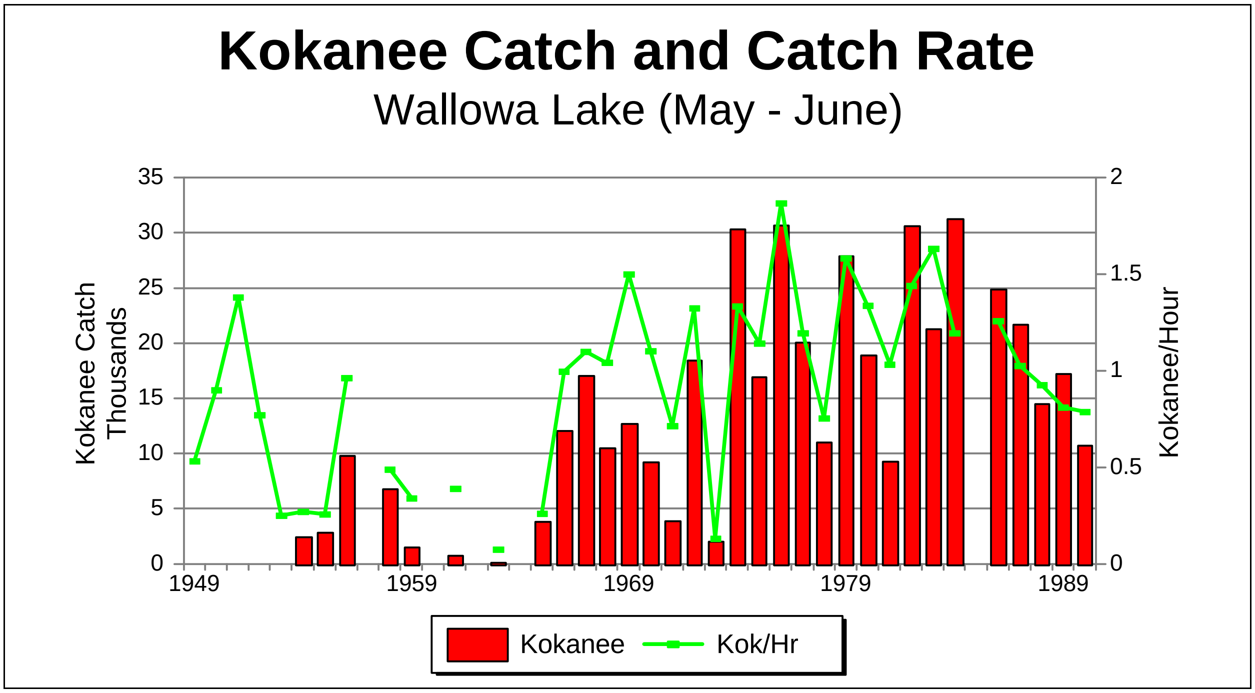


Figure 16. Total catch and mean catch per hour of kokanee during May and June by boat anglers in Wallowa Lake, 1949-90 (estimates by ODFW).

Table 5. Observations of kokanee spawners in the Wallowa River and Indian Creek During 1952-1967.

Year	Date	Kokanee	Redds		Year	Date	Kokanee	Redds
1952	---	5,000 - 8,000	---		1961	17-Sep	60	0
					1961	20-Sep	0	1
1953	07-Oct	58	26		1961	08-Nov	131	38
1953	15-Oct	268	139					
					1962	01-Dec	12	0
1954	---	Few	---		1963	10-Dec	22	95
1955	---	Few	---		1964	Dec	4,000	---
1956	---	Many	---		1965	---	5,000	---
1957	---	3,000	---		1966	---	10,000	---
1958	---	No counts	---					
1959	---	No counts	---		1967	01-Sep	10,000	---
1960	---	No counts	---		1967	01-Nov	3,000	—

It is instructive to examine the causes of the kokanee population collapse to avoid similar situations if sockeye are reintroduced. Two important events coincided with the collapse. First, the Oregon State Highway Commission channelized 1.25 miles of the Wallowa River down to its confluence with the lake in 1950 to control flooding in the state park. Before channelization, there was a maze of small channels across the alluvial plain where kokanee spawned (Toner 1960). The Oregon Game Commission area biologist reported that no kokanee entered the river to spawn in 1951 (mimeographed report, Enterprise). Two spawning channels 1/4 miles long were constructed through the state park in 1955. Two more channels were added in 1959. In 1963, the highway Department excavated a portion of the channel to make 400 ft of flat channel. Spawners were counted in the channel and river during 1952-67. A few hundred spawners or less were observed in 1961-63, but 4,000 spawners were observed in Indian Creek and along the northeast shore of the lake in 1964 (Table 5). Indian Creek is a spring fed stream that originates near the Wallowa Lake Lodge. The stream is very short; about 150 yards long during the kokanee spawning period. Because Indian Creek is spring fed, its water temperature during the kokanee/sockeye spawning period may differ from that of the Wallowa River.

Although channelization eliminated important spawning areas, several pieces of evidence indicate this alone did not cause the collapse of the kokanee population. While channelization was completed in 1950, the lowest point in the population occurred in the early 1960's, as evidenced by largest spawners (Figure 13), lowest angler catch (Table 4), and few spawners observed. Angler catch and spawner counts indicate the population of maturing kokanee in 1956 was sizable. The group spawning in 1956 would have been produced by the 1952 brood which also had many spawners (Table 5). Only 19,750 fry were stocked in 1953, by far the least of any year between 1953 and 1958 (Appendix 8). Thus, it appears that significant reproduction was possible with the spawning areas existing after channelization.

An event that coincided with the collapse of the kokanee population was the introduction of lake trout during 1956-61 (Table 6). Lake trout appeared in the catch during 1957-1964 and were essentially gone by 1956, just as the kokanee population, with the aid of intensive stocking, was recovered (Figure 17). Lake trout prey heavily on kokanee. The strong impact that lake trout can have on kokanee was demonstrated in Priest Lake, Idaho where the lake trout fishery went from a catch of 138 fish in 1970 to 5,724 in 1978, while the kokanee harvest went from 79,840 in 1970 to 4,593 in 1978 (Mauser et al.1988). Kokanee accounted for 1/3 of the diet of lake trout in 1978 (Mauser et al.1988).

The collapse of the kokanee fishery and the increase in the lake trout harvest coincides with the introduction of opossum shrimp, *Mysis relicta,* in Priest Lake beginning in 1965. While the kokanee population declined, lake trout benefitted from *M. relicta.* Bowles et al. (1991) believe that lake trout were a key factor in the collapse of the kokanee population in Priest Lake. As kokanee recruitment declined from competition with *M. relicta,* the piscivore population increased (Bowles et al. 1991).

Table 6. Number and size of lake trout planted in Wallowa Lake.

Year	Lake Trout	Length(inches)
1956	9,079	5.0
1957	2,424	6.0
1958	64,425	4.0
1959	65,788	4.0
1960	33,897	4.0
1961	32,620	4.0
Totals	**208,233**	

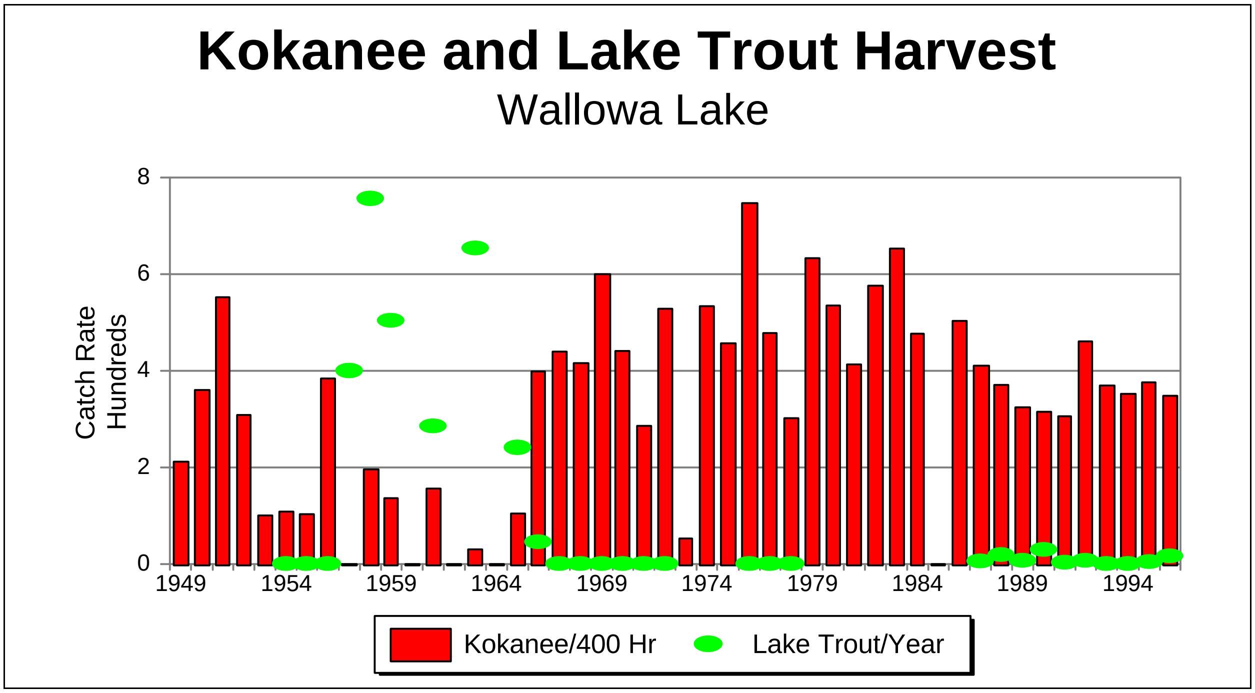


Figure 17. Relative abundance of kokanee and lake trout in Wallowa Lake each year, 1949-90, as indexed by catch of kokanee/400 boat-angler hours in May-June and total catch of lake trout during April-October (estimates by ODFW).

Mysis were first introduced into Wallowa Lake in 1965 as a new food base to grow larger kokanee. In some lakes, introductions of mysis have triggered large changes in the zooplankton communities, including disappearance of *Daphnia* and declines in other cladocerans (Zyblut 1970; Richards et al. 1975; Morgan et al. 1978; Goldman et al. 1979; Kinsten and Olsen 1981; Langeland 1981, 1988; Rieman and Falter 1981; Martinez 1986; Nero and Sprules 1986). Growth and abundance of planktivorous salmonids, notably kokanee, in these other lakes declined sharply after *M. relicta* became established (Richards et al. 1975; Morgan et al. 1978; Rieman and Bowler 1980; Rieman and Falter 1981). Where lake trout were present, they preyed on the slower growing kokanee after *M. relicta* become established and the lake trout population expanded (Bowles et al. 1991; Northcote 1991; Beattie et al. 1991). At the present time, we believe populations of lake trout and *M. relicta* have stabilized in Wallowa Lake without any adverse impact on the kokanee population. We conclude that any increase in lake trout or *M. relicta* populations in Wallowa Lake would likely impede kokanee recruitment and any effort to reintroduce sockeye salmon.

Estimates of Kokanee Production

Estimates of kokanee production in Wallowa Lake can be useful for comparison to theoretical models of the lake's productive capacity for sockeye smolts. We developed an estimate of the production of the 1986 brood kokanee in Wallowa Lake based on the comparative data for harvest rates of kokanee in Odell Lake, Oregon. Secchi depths in Odell lake range from 22 ft to 35 ft (Lindsay and Lewis 1978) compared to 28 to 45 ft in Wallowa Lake. Rieman and Meyers (1990) found secchi depth to correlate well with several measures of lake productivity for kokanee. Angler effort per surface area is also similar between Odell and Wallowa Lakes. Boat angling effort at Wallowa Lake ranged from 13,000 to 26,000 hours during May 15 - June 30 of 1982-86. This equates to 39,000 to 78,000 hours for the full season (see effort ratios in Table 3). At Odell Lake, which has 2.4 times the surface area of Wallowa Lake, angler effort ranges from 60,000-200,000 hours per year. Based on these similarities, we assumed that harvest rates of kokanee in Wallowa Lake are similar to those at Odell Lake.

Lindsay and Lewis (1976) did not estimate harvest rates in Odell Lake, but they provided the necessary data. First, to confirm that harvest rate was related to angler effort, we compared the ratio of catch at age 2 to age 3 of a cohort to the ratio of angler hours in the years the fish were caught, and found a significant correlation (Figure 18). This correlation indicates that catch is a function of effort for both age 2 and age 3 fish. We back calculated the abundance at each age of Odell Lake kokanee by using the Lindsay and Lewis (1976) estimates of catch and escapement at each age and by assuming survival, excluding fishing mortality was, 70% each year between ages 0+ to 2+ and 80% between ages 2+ and 3+. These estimates of survival were based on estimates of survival from age 1+ to 2+ at Pend Orielle, Spirit, and Coeur d'Alene Lakes of 58%, 69% and 91%, respectively (Bowler 1981; La Bolle 1986; Mauser et al. 1988). Lindsay and Lewis (1976) estimated that spawning in Shelter Cove represented 32% of the total in the lake, so I used this proportion to expand spawning estimates in Shelter Cove during 1974-76 (Lindsay and Lewis 1978) to those for the whole lake. Under these assumptions, estimated harvest rate for age 3+ ranged from 37% to 61% for the 1970 through 1972 broods and averaged 50% (Table 7). Harvest rate at age 2+ was near 8% for all three broods. Thus, age 3 fish were about six times more vulnerable to harvest than age 2. This is congruent with the findings of Rieman and Meyers (1990) that catchability is an exponential function of length.

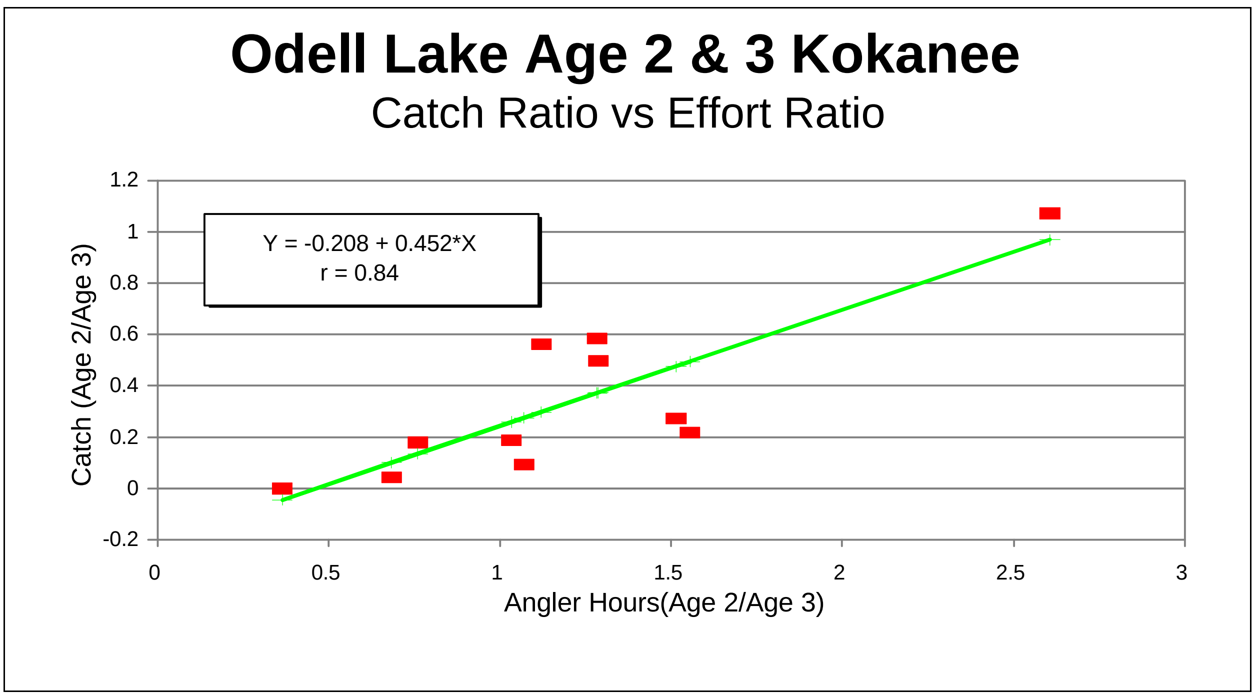


Figure 18. Relationship of kokanee catch to angler effort in Odell Lake as determined by the ratio of catch and effort for age 2 fish in year i and age 3 fish of the same brood in year i + 1 (data from Lewis and Lindsay 1976, and Lindsay and Lewis 1978).

Table 7. Kokanee abundance and harvest at age in Odell Lake, based on Lewis and Lindsay (1976), and estimated harvest rate.

Brood	Catch (a)		Total Brood	Estimated	Harvest Rate(c)	
Year	Age 2+	Age 3+	Harvest	Spawners(b)	Age 2	Age 3
1960		88,426	88,426			
1961	24,940	27,816	52,756			
1962	28,952	26,989	55,941			
1963	2,031	47,631	49,662			
1964	0	88,145	88,145			
1965	3,673	39,103	42,776			
1966	18,401	31,427	49,828			
1967	20,952	42,062	63,014			
1968	9,943	55,233	65,176			
1969	33,853	60,109	93,962			
1970	10,608	56,637	67,245	36,562	0.083	0.608
1971	4,925	17,914	22,839	30,312	0.076	0.371
1972	2,404	10,975	13,379	10,312	0.083	0.516
1973						
1974						
1975						

(a) Age composition of catch from Lewis and Lindsay (1976)

(b) Estimated based on spawner estimates for Shelter Cove (Lindsay and Lewis 1978). I assumed Shelter Cove had 32% of spawners, based on estimates that 46% and 18% of fry were from Shelter Cove in 1975 and 1976. I used 46% spawners in Shelter Cove for 1975 year class based on direct estimate.

(c) Back calculated based on all fish maturing at age 4 and 20% natural mortality between age 2+ and 3+. See text for explanation.

Because vulnerability is a function of fish size, it is important that harvest rates only be assumed similar when fish sizes are similar. Age 2+ fish in Odell Lake were generally 21-22 cm and age 3+ were 25-30 cm. Age data from angler caught kokanee in Wallowa Lake are available for 1986-1989 (Table 8) and show an average length of 28 cm at age 3+ in 1988, similar to kokanee in Odell Lake. We made a rough estimate the number of fish at each age in the catch by assuming that the proportion of fish at each age was the same as that found from the scale samples. Older and larger fish are slightly over-estimated by this assumption, because fish were sampled to determine length/age relationships, not to represent length frequency of the catch. The extent of this bias cannot be determined, but the small percentage of age 4 fish estimated during 1987-89 (Table 8) indicates the bias was probably small. Given the estimate of 17,772 age 3 kokanee caught in 1987, these fish would have represented an age 3 population of 33,500 if the harvest rate was 50%. We used the same assumptions as for Odell Lake kokanee to back-calculate the population at each age in Wallowa Lake, prior to harvest. The results in Table 9 indicate the biomass of the cohort, if all ages were in the lake at the same time, would have been about 12,000 kg. Wallowa Lake should support substantially more biomass than this, because the large increase in mean length at maturity indicates the population was at a low level compared to previous years.

Table 8. Age composition of kokanee harvested from Wallowa Lake during 1986-1989. (Note: older and larger fish are over-represented in this information. Fish were sampled to determine length/age relationships, not to represent length frequency of the catch. Accuracy would be improved by collecting a representative length-frequency sample of the population.)

	1986		1987		1988		1989	
Age	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**
2	25%	6,250	10%	2,222	16%	2,460	52%	8,943
3	29%	7,250	80%	17,772	76%	11,687	37%	6,363
4	44%	11,000	10%	2,222	8%	1,230	11%	1,892
Total		**25,000**		**22,215**		**15,378**		**17,198**

Table 9. Estimated abundance and biomass of the 1984 brood kokanee at each age in Wallowa Lake. See text for derivation.

Year	Age	Number Alive May 1	Approximate Mean Weight Per Fish(g)	Weight of Cohort (kg)
1988	4+	2,843	500	1,422
1987	3+	35,500	160	5,680
1986	2+	48,234	90	4,341
1985	1+	60,292	12	724
1984	0+	82,132	0	25
			Summed Biomass	**12,191**

Note: Assumed survival of .7, .8, .8, .8 following ages 0,1,2,3.
Assumed maturity rates of 0.8 and 1.0 at ages 3+ and 4+.

Culture of Kokanee

Kokanee eggs were taken in Wallowa Lake and reared at Wallowa Hatchery for fry releases back into the lake in most years during 1922-1942 (Appendix 8). Spawning stock was generally obtained by seining maturing kokanee at the mouth of Indian Creek at the head of the lake (personal communication on 10/3/90 with John Rayner, Oregon Game Commission biologist for Wallowa Lake during the early 1940's). Numbers of eggs taken were highly variable between years, exceeding 5 million eggs in 1924, 1926, and 1932, but dropping to under 100,000 in 1933, 1939, and 1941. Non-native kokanee were first introduced sometime between 1942 and 1955; the source of plants during these years is not indicated in the records (Appendix 8). Substantial numbers of kokanee from Montana, Washington, and British Columbia have been planted in the lake between 1955 and 1982. Beginning in 1990 through 1994, a small number of fin marked hatchery kokanee were released into Wallowa Lake to (1) measure the contribution of marked kokanee to the fisheries over time (2) to determine if natural kokanee population were declining after the establishment of *M. relicta,* and (3) establish a hatchery supplementation program to support the kokanee fishery if the kokanee population were declining. It was determined that the natural population was self-sustaining (personal communication with Bill Knox, ODFW, Enterprise).

Evidence indicates these introductions have altered the gene pool of kokanee in Wallowa Lake. It appears that the native stock was almost entirely replaced by introduced stocks after the Wallowa Lake kokanee population dropped to near zero during 1959-1963. During several years, no kokanee were observed in the spawning areas (see Table 5), although thousands were typically seen previously. An aggressive stocking campaign with stocks imported from Washington, Montana and British Columbia was initiated in 1962 when 531 lbs of fingerlings were planted. Prior to 1962, plantings had rarely exceeded 100 lbs (Appendix 8). Over 1,100 lbs were stocked in 1963, over 1,200 lbs in 1964, and over 1,700 lbs in 1965. By 1964, the estimated number of kokanee spawners had jumped back up to 4,000 and the annual catch of kokanee by anglers jumped from 303 in 1963 to 5,190 in 1965 and to 13,223 in 1966.

A portion of the fish released during 1965-1970 were marked and it was estimated from mark recoveries by anglers that 69.4% of the catch in 1967 was hatchery fish planted in 1965 (Appendix 9). The remaining 30.6% of the catch was probably offspring from the 1964 spawning that resulted from the 1962 planting (the 1962 planting was yearlings that would have been age 4 and spawned in 1964). The proportion of hatchery fish in the catch declined to 5.5% in 1970 and 2.4% in 1971 as the offspring of spawners in 1965-67 began to dominate the catch. Thus, it appears from this sequence of events in 1960-1967, that most of the gene pool of kokanee in the lake may have been replaced by imported stocks.

The influx of genetic material from these new stocks was also apparent at the time of spawning. In 1964, when the yearlings planted in 1962 would have spawned, only 52 redds were observed in the Wallowa River during September, the typical time and location of spawning previously. However, over 4,000 kokanee were observed spawning in December in the Indian Creek channel and southwest shore of the lake, but not in Wallowa River (ODFW records, Enterprise). We deduce that imported kokanee in 1962 were seeking warmer waters found in the Indian Creek springs and were late spawners. Spawners in December also differed morphologically from those in September. September spawners tended to have red bodies with dark heads in contrast to December spawners which had olive bodies and red caudal peduncles (ODFW records, Enterprise). Spawning activity in the Wallowa River in recent years has been greatest in September, as would be expected due to poor survival of eggs deposited there during low temperatures in November and December. The ancestral source of the remaining kokanee is likely to be mixed, because kokanee from a variety of stock origins have been stocked in Wallowa Lake since the early 1960's (see Appendix 8). Genetic sampling should be completed to obtain a genetic profile of the spawning groups now present in Wallowa Lake, and determine if there are indications that the native stock has persisted.

CONDITION OF SOCKEYE HABITAT

Physical Characteristics

At the present time, a substantial challenge lies in getting fish between Wallowa Lake and the ocean. In addition to obstacles along the migration route, sockeye would also be challenged by a different biological environment in the lake than existed before 1900. We will review habitat as it affects each life stage, beginning with spawning.

Spawning Habitat

Accounts of sockeye spawning in the lake indicate they spawned both in the river above the lake and along the shore of the lake near the inlet. It is likely that separate stocks would have evolved for these two locations because of differences in temperature the eggs would be exposed to. Larson (1973) found during the summer that the inflow was generally 7°-8°C cooler than the lake surface temperature. Similarly, Toner (1960) found during 1959 that inflow temperatures reached a maximum of 13°C, while lake surface temperatures reached in excess of 22°C. Temperatures in the lake rarely drop below 4°C, except at the surface in the winter, while temperatures in the river often approach freezing. Therefore, one would expect adapted stocks to spawn earlier in the river than in the lake in order to emerge at the proper time in the spring. This appears to be consistent with observations of the spawning times of kokanee in the river (peak spawning in mid September) and lake (peak spawning in November), although kokanee have been observed in recent years spawning in the river in late October (personal communication with Bill Knox, ODFW, Enterprise).

A lakeshore spawning stock will be challenged by fluctuating water levels in the fall.

Ideal spawning gravels might be too deep for preferences of the fish in some years. Lake levels rarely drop to that of the undammed lake. Lake levels at the end of September and October vary from 5 ft to 23 ft (see Figure 9). Data are not available to evaluate the reduction in spawning production this might cause. Dewatering of redds as a result of dropping lake levels is also a concern; however, the water level dropped more than 2 ft between September 30 and February 28 in only 3 of the last 50 years. The biggest drop occurred in 1982-83 when the lake level dropped from 23.4 ft on October 31 to 19.12 ft on February 28. We conclude that dewatering of some redds would occur less than once in 10 years.

The continued spawning of kokanee in some areas of the lakeshore indicates spawning habitat exists to support a viable population, although its potential may be reduced by the fluctuations in lake level. No attempt has been made to estimate the number of kokanee spawning in shore areas. This is a difficult proposition, first because spawners are difficult to see in the lake and second because many fish only move in to shore to spawn at night (Lewis and Lindsay 1976).

Spawning area in the Wallowa River within 1 mile upstream of the lake has been reduced by the channelization project in 1950. Natural recruitment of gravel by the river has restored much of this spawning area, although not to its former quality or quantity level. Spawning habitat has been judged by ODFW biologists to be sufficient for kokanee and the artificial spawning channels are no longer maintained. The success of natural production in the river indicates spawning area is not severely limiting for kokanee, although the degree to which it does limit production cannot be determined from existing data. At the present time there is considerable imposition of kokanee redds. The present condition, quantity and quality, of available spawning habitat may not meet the needs of both kokanee and sockeye. The spawner capacity of the Wallowa River above the lake should be estimated by stream survey to assess this potential.

Habitat for Rearing and Downstream Migration

Once sockeye emerge from the gravel and enter the lake for rearing, they will find the water quality as pristine as in 1900. Larson (1973) concludes from his study of the lake that it is "unpolluted, uncontaminated," and ranks high among good quality lakes in Oregon.

We were concerned that sockeye smolts may be delayed in exiting the lake in some years, because of the depth smolts must dive to reach the outlet. This has been a problem with reintroduction of sockeye into Cle Elum Lake, Washington, but it turns out that fish there must dive in excess of 100 ft. In Wallowa Lake, the water level on April 30, near the peak time of smolt emigration, varies from 10 ft to 27 ft (see Figure 8). Because the lake outlet is at 0 ft, smolts will have to dive to enter the outlet. This may delay smolts in some years when the reservoir is near full, but not spilling. However, this should be a minor problem, if at all, because studies of sockeye smolts approaching Columbia River Dams indicate they distribute deeper in the water column than other salmonids in the Columbia (Olson 1984).

Engineering solutions will be required to get smolts safely past the many irrigation diversions (unscreened) immediately below the lake. Several diversion pipes exit directly from the reservoir, including the Silver Lake Ditch flume which withdraws 0 to 130 cfs. The Farmers Ditch diverts 0-150 cfs about 200 m below the dam. Consolidated Ditch begins about 1.5 miles below the dam and diverts 0-400 cfs. While these ditches divert small amounts of water year-round, they do not begin diverting large flows for irrigation until late May or early June (Figure 19). However, there may be a lack of adequate fish transportation flows in the Wallowa River immediately below the dam in April while the lake is still filling and irrigation has not started. Present legislation requires owners of the canals diverting more than 30 cfs to provide adequate screening if the State deems that screens are necessary. Legislation proposed in 1997 would amend this requirement allowing for public funds to screen diversions. Unscreened canals directly below Wallowa Lake will be screened if the need is identified (A. Schumacher, ODFW, personal communication, March, 1997). We proceeded with the analysis under the assumption these problems can be solved by negotiation of water use and by capital investment in fish screens.

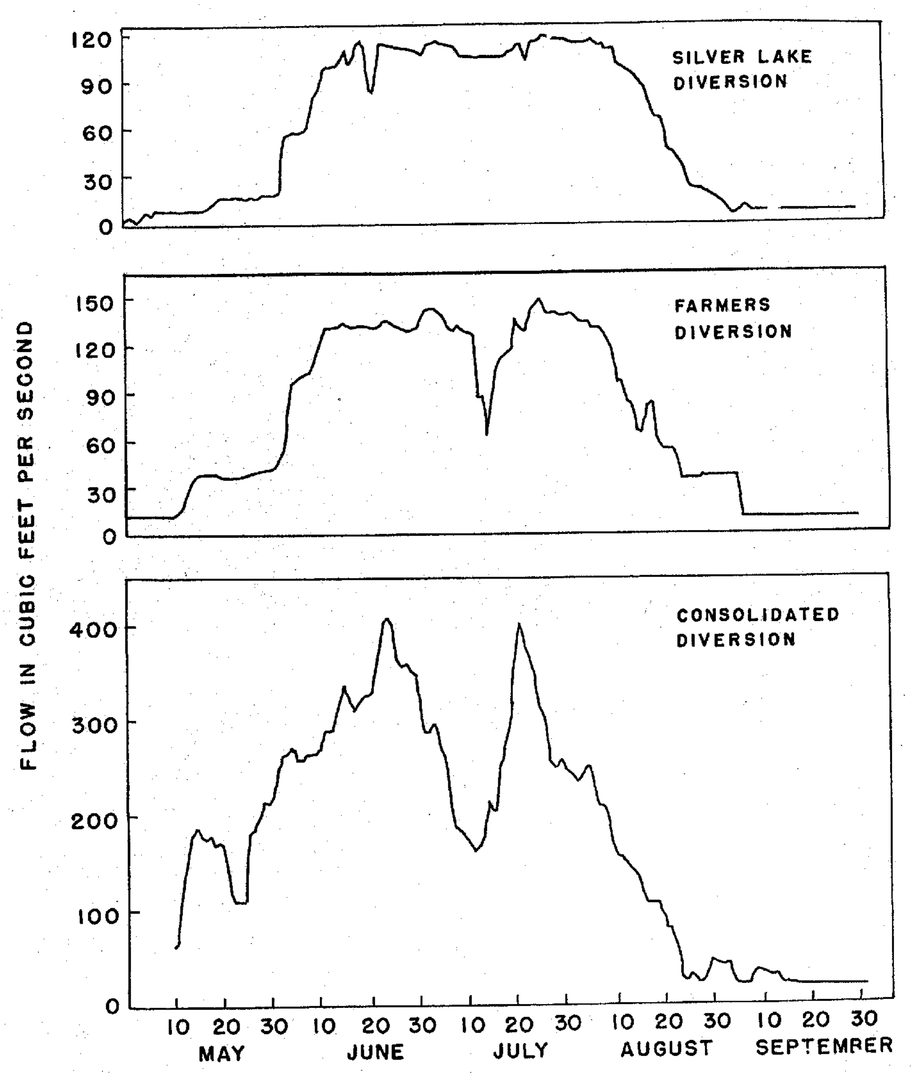


Figure 19. Daily flows from Wallowa Lake into Consolidated, Farmers, and Silver Lake Diversion ditches during the irrigation season, May-September, 1959 (from Toner 1960).

Temperatures and flows during mid April to mid June (see Figures 2-5) are well suited to outmigration of smolts from the Grande Ronde basin, but then smolts must pass through the gauntlet of eight dams on the Snake and Columbia River. The success of sockeye from Lake Wenatchee above seven dams and Lake Osoyoos above nine dams proves that passage is possible. Mullan (1986) estimated adult Lake Wenatchee sockeye declined about 50% after 1947-57. He attributed the loss to turbine mortality at seven mainstem dams. Chapman et al. (1990) estimated a 74-81% smolt loss at dams for Redfish Lake sockeye. Bowles and Cohnauer (1984) estimate a 0.815 per dam survival for sockeye smolts, based on the estimate by Bjornn et al. (1968) that smolt to adult survival for Redfish Lake sockeye averaged 0.008 during 1955-64. However, the combination of numerous improvements to fish passage facilities at Snake and Columbia River dams over the past two decades is likely to have increased passage survival of sockeye smolts. Recent estimates of chinook smolt survival past Snake River dams indicate that survival rates range from 55% to 90% across four dams (Cramer 1996; Muir et al. 1995), which is substantially higher than estimated during the 1970's by Raymond (1979). Chapman et al. (1995) pointed out that sockeye smolts probably suffer greater mortality at dams than chinook smolts, so we have conservatively assumed a 10% mortality per dam for our modeling. Over eight dams, this equates to 43% survival of smolts from Wallowa Lake to ocean entry.

This survival may be improved by transportation. Bowles and Cochnauer (1984) estimated the transportation benefit was 1.5 from McNary to below Bonneville, but was 3.25 past Snake River dams to below Bonneville, based on 8 years of data from Park (1980) and Irving and Bjornn (1981). Although transportation may be beneficial, Chapman et al (1990) estimate that collection efficiency for sockeye smolts at Lower Granite Dam is only about 33%, because sockeye tend to move deep in the water column and under the fish guidance screens. Bowles and Cochnauer (1984) estimated a 45% collection efficiency, but their estimate was based on tests with spring chinook, and they assumed sockeye would behave similarly. Carlson et al. (1989) estimated the transportation benefit ratio for sockeye from the 1984 and 1985 broods trapped at Priest Rapids Dam and barged to below Bonneville was 1.7:1. However, homing was impaired so that escapement of test and control groups was equal. We conclude that escapements will not be improved significantly by transporting smolts.

In addition to reduced survival as smolts migrate through the Snake and Columbia Rivers, their migration will also be delayed. Delays in migration are likely to further reduce survival as sockeye are exposed to increasing river temperatures and, therefore, disease and predation rates.

Once in the ocean, conditions will probably be similar to those prior to 1900. Recent data from CWT studies with Wenatchee and Osoyoos sockeye indicate ocean harvest of those stocks is nil (Carlson et al. 1989). Marine mortality estimates for different stocks and brood years of sockeye salmon range from 50% to over 95% (Burgner 1991). Generally, smolts of larger size will experience higher marine survival (Hyatt and Stockner 1985). Variations in oceanographic conditions and in marine predator populations affect marine survival, but these effects are poorly understood (Burgner 1991). Rogers (1984) hypothesized that differences in winter ocean temperatures result in differences in winter distribution of sockeye and in their vulnerability to marine predators.

Environment for Upstream Migration

Upstream migration of sockeye will be impaired by the eight mainstem dams; however, this problem has obviously been overcome by the Lake Wenatchee and Lake Osoyoos stocks. Bowles and Cochnauer (1984) estimated 0.92 survival of adult sockeye past each dam, based on 5 years of data past 3 to 8 dams. In addition to mortality at each dam, Chapman et al. (1990) noted substantial prespawning mortality of Redfish Lake sockeye in the Snake River, based on differences in counts of fish passing Ice Harbor Dam and those reaching Redfish weir during 1963-66. On average, only 22% of the fish crossing Ice Harbor showed up at Redfish weir. After considering extenuating circumstances affecting the counts, Chapman et al. (1990) recommend 25% be used as a provisional estimate of prespawning mortality. A prespawning mortality of at least this magnitude is likely in the Grande Ronde Basin.

Timing of sockeye entry into the Grande Ronde River is an important factor, because fish entering after mid July are likely to encounter potentially lethal river temperatures (Figure 20). Most sockeye historically passed Troy (RM 46) between June 20 and July 20 (Van Dusen 1903). As a point of comparison, counts of sockeye at McNary Dam during 1956-1989 show sockeye begin passing in early June and peak in early July (USACE 1990). However, McNary Dam (RM 292) is still 201 miles downstream from the mouth of the Grande Ronde River. Allen and Meekin (1973) reported that sockeye entry into the Okanogan River (leading to Osoyoos Lake) was delayed when water temperatures exceeded 70°F, and prespawning mortality was substantial in some years; however, the Okanogan River and Lake Osoyoos continue to produce a large run of sockeye. Temperature recordings for the Okanogan River, presented by Allen and Meekin (1973), show daily average temperatures exceed 70°F and reach 80°F during August, the peak month of adult sockeye migration into the river. These temperatures in the Okanogan River are similar to those in the Grande Ronde River.

It appears from the Okanogan study (Allen and Meekin 1973) that sockeye may be able to successfully migrate through the lower Grande Ronde during August by waiting for periods of reduced temperature (Figure 20). Sockeye are also likely to overcome high river temperatures by locating areas of cool groundwater seepage where they can hold temporarily. Dr. Thomas Quinn, found from radio tagging studies in the Yakima River that adult chinook were able to maintain body temperatures up to 12.5°F lower than the river temperature and averaged 4.5°F lower by holding in cool water seepages (paper presented at the Oregon American Fisheries Society meeting 1991).

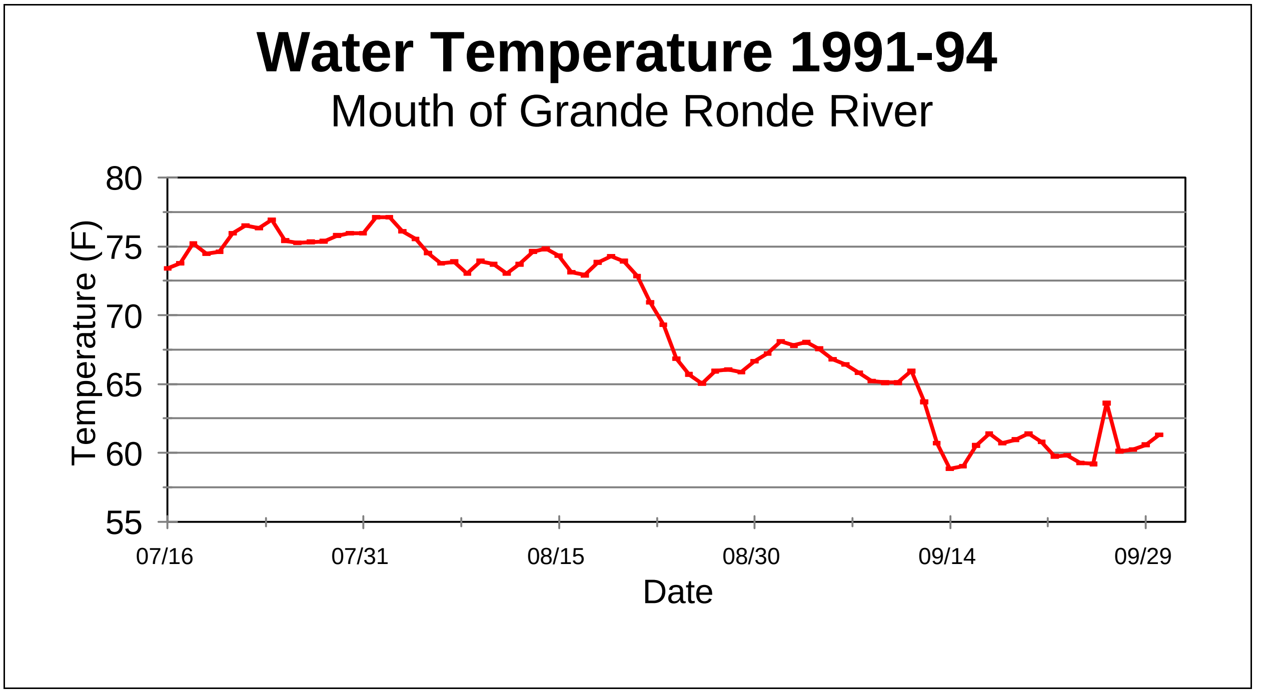


Figure 20. Water temperature collected by Idaho Power Company at the mouth of the Grande Ronde River during August through September 1991-94 (Data obtained from Billy Connors, USFWS)

The Grande Ronde River is cooled some by the entry of the Wenaha River 46 miles upstream, although temperatures in the Wenaha only run about 5°F cooler than the Grande Ronde during July (Figures 21 and 22). Spot temperatures measured in the Grande Ronde in July and August 1959 near Troy were never above 67°F in the morning and were generally 60°-63°F in the morning (Thompson and Haas 1960). Temperatures of the Grande Ronde at Rondowa (see Figure 5) where the Wallowa River enters (RM 82), also may be stressful in late July, although daily minimums drop to the low 60°'s F. Thompson and Haas (1960) also recorded temperatures in the Wallowa River at RM 13, 3 miles above Minam and found that daily maximums occasionally reached 70°F in July, but minimums generally dropped to the low 50°'s F daily (Figure 23). Once sockeye have reached Rondowa, the daily maximum temperatures will be stressful, but the rapid cooling at night should enable fish to survive through most summers. We conclude that high river temperatures are likely to delay migration and cause prespawning mortality in some years, but sockeye should be able to overcome these problems as they have in the Okanogan River.

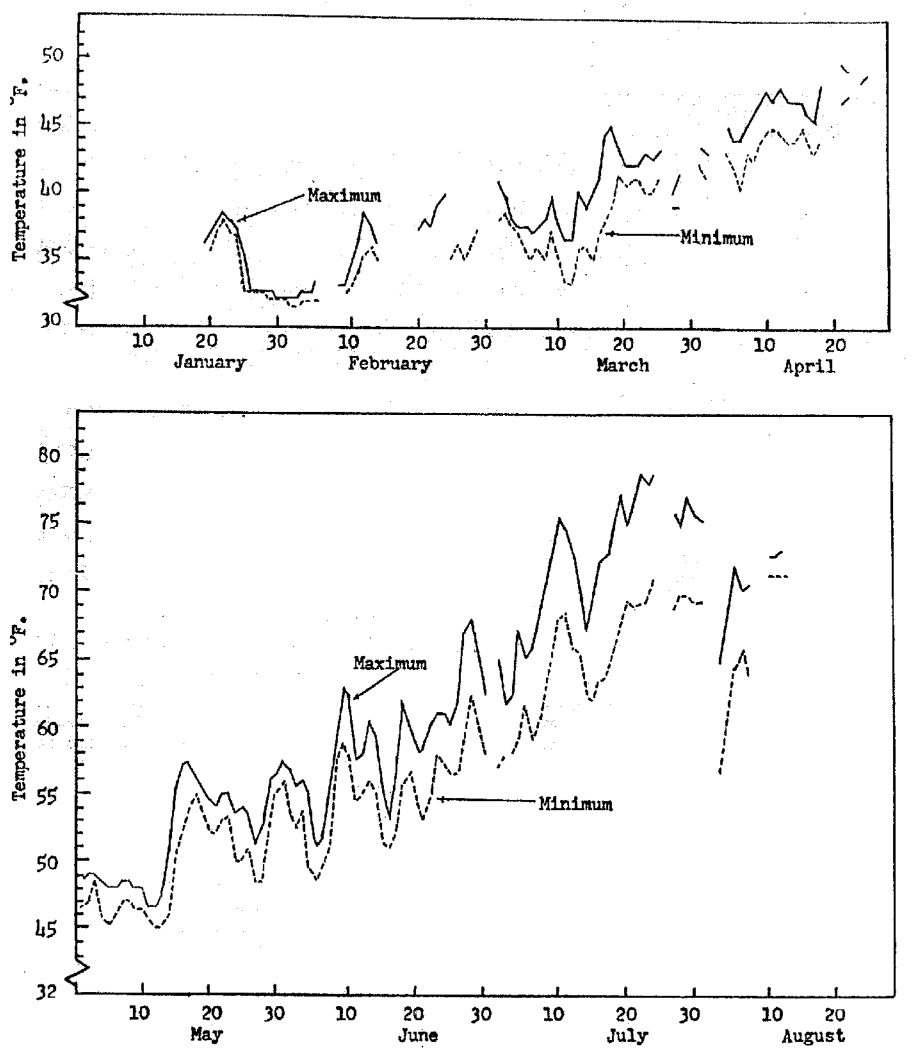


Figure 21. Daily maximum and minimum temperatures of the Grande Ronde River at rm 27 during January-August, 1956 (from Thompson and Haas 1960).

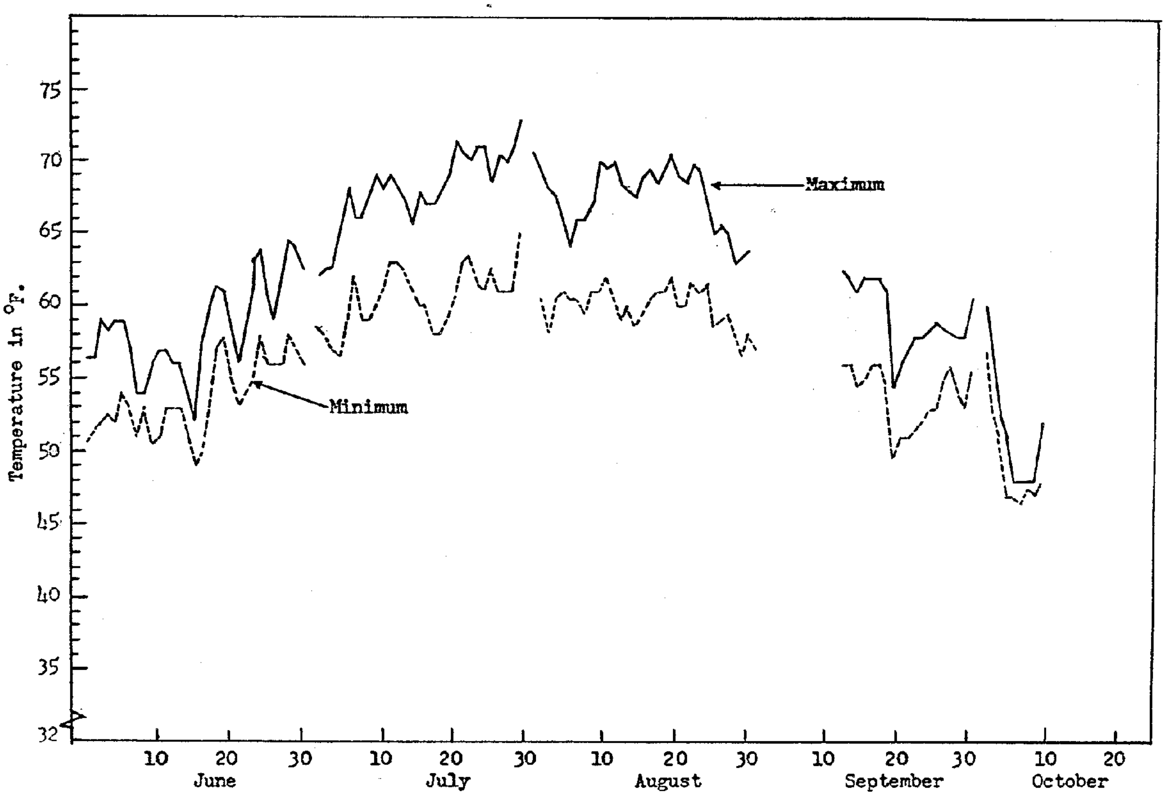


Figure 22. Daily maximum and minimum temperatures of the Wenaha River at its mouth during June-October, 1957 (from Thompson and Haas 1960).

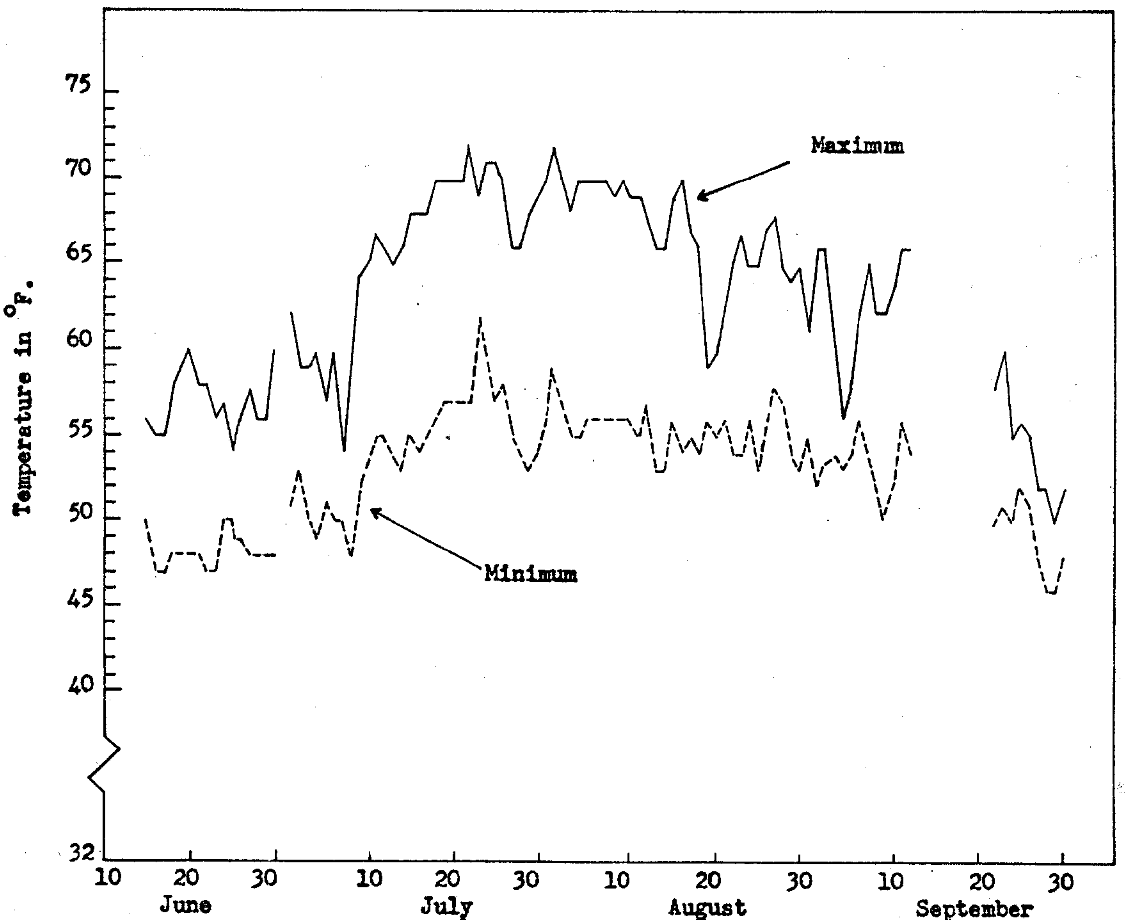


Figure 23. Daily maximum and minimum temperatures of the Wallowa River, 3 miles above Minam during June-September, 1959 (from Thompson and Haas 1960).

Entry to the Lake

Once fish have navigated their way up the Wallowa River, they still may face a dewatered river near Joseph. Matson (1958) reports that during July-September,

> "The area between these two ditches (Big Bend and consolidated) and the Wilson and Miller Pond Ditches, located 1/4 miles below, generally carry between 8 and 10 second-feet of water. The greatest problem, however, exists in the channel between the Wilson and Miller Pond Ditches and a point about 1 miles downstream. This area is almost entirely dewatered."

Toner (1960) also calls attention to this problem and indicates that ditch operators may be willing to provide minimum flows of 15 cfs, the flow recommended by Matson (1958) to accommodate fish passage.

Entry into the lake is blocked by Wallowa Lake Dam which is approximately 36 ft high. Solutions for getting fish over this barrier should be worked out by engineers experienced in the design of fish passage facilities. Any fish passage facility must take in to account the variable water level. Water levels on July 31 vary from 5 ft to 27 ft (see Figure 8).

An Alaskan Steeppass Fishway is an inexpensive alternative that should be considered for fish passage over the dam. A Steeppass fishway has been used at Frazer Falls to pass 100,000's of sockeye in one season (Blackett 1987). The fishway had a 22% slope over a 60 m distance, and fish showed no signs of fatigue in reaching the top.

Biological Characteristics

Forage

The forage base for juvenile sockeye in Wallowa Lake has changed with the introduction of the opossum shrimp, *Mysis relicta*, in 1965-67 (Stout and Swan 1967). However, the Mysids did not begin to show up in fish stomachs until about 1985 (personal communication with Ken Witty, ODFW, Enterprise). *Mysis relicta* can serve as excellent forage for fish, but are themselves predators on cladoceran zooplankton, the preferred food item of young kokanee (Koenings and Burkett 1987). Introduction of *Mysis* in some lakes has had a dramatic impact on the zooplankton and fish populations (Lasenby et al. 1986). A highly successful introduction of *Mysis* into Kootenay Lake in 1949-50 resulted in substantial increases in growth of kokanee beginning in the early 1960's (Northcote 1972). This prompted introductions of *Mysis* elsewhere in hopes of similar results.

Introductions of *Mysis* into Lake Tahoe during 1963-65 resulted in an established Mysid population by 1971, but the kokanee population never increased even to level to stimulate a fishery (Morgan et al. 1978). Instead, the Mysids competed with the kokanee for cladocerans, and the three dominant cladoceran species disappeared from the lake.

Rieman and Falter (1981) report a similar experience in Pend Oreille Lake, Idaho. There, Daphnia spp. and Bosmina spp. were historically abundant in April through October, but predation by introduced Mysids kept them at low abundance until late July or August. Abundance of copepods, also a common food of kokanee, was not affected. Copepods are generally larger than cladocerans and probably too large for consumption by M. relicta. Koenings and Burkett (1987) showed that sockeye fry foraged selectively on Daphnia and Bosmina and were ineffective at preying on the copepods, Cyclops spp. and Diaptomous spp. However, as sockeye grow they later predominantly consume copepods and their growth rate has been related to densities of Cyclops in Pend Orielle Lake (Rieman 1981) and Odell Lake (Lindsay and Lewis 1978). Rieman and Falter (1981) found Mysids concentrated near the surface at night during February-June, but Mysids were restricted to depths below 10 m during August and September, apparently in response to temperature. Cladocerans were restricted to the upper 10 m throughout the summer. Rieman and Falter (1981) concluded that only after mid-summer when thermal stratification caused vertical separation of Mysids and cladocerans were cladocerans able to rapidly expand in abundance. Abundance of Daphnia and Bosmina in Wallowa Lake now follow a pattern similar to that described in Pend Orielle Lake. In fact, abundance of Daphnia has peaked later each year since 1987, and they never became abundant in 1990 (Figure 24). The abundance of *M. relicta* appears to have fluctuated, and reached its highest abundance in the spring of 1991, the last year of sampling (Figure 25).

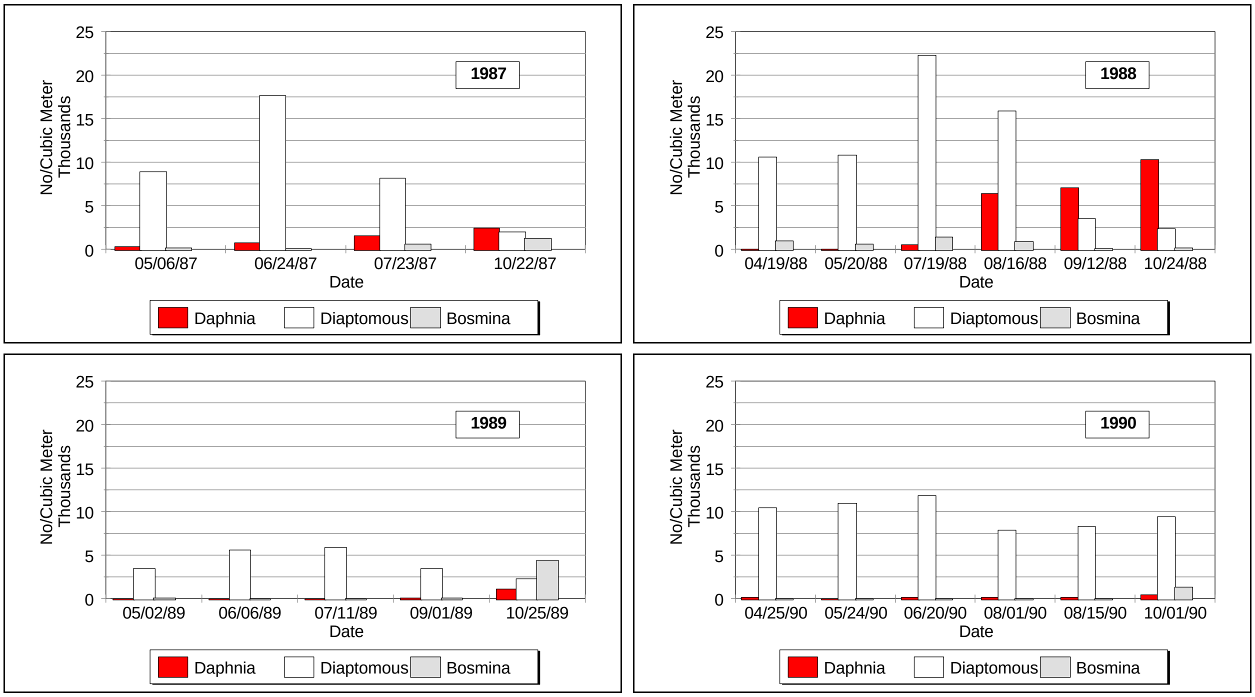


Figure 24. Densities of zooplankton averaged from standard tows at three stations in Wallowa Lake (data collected by ODFW).

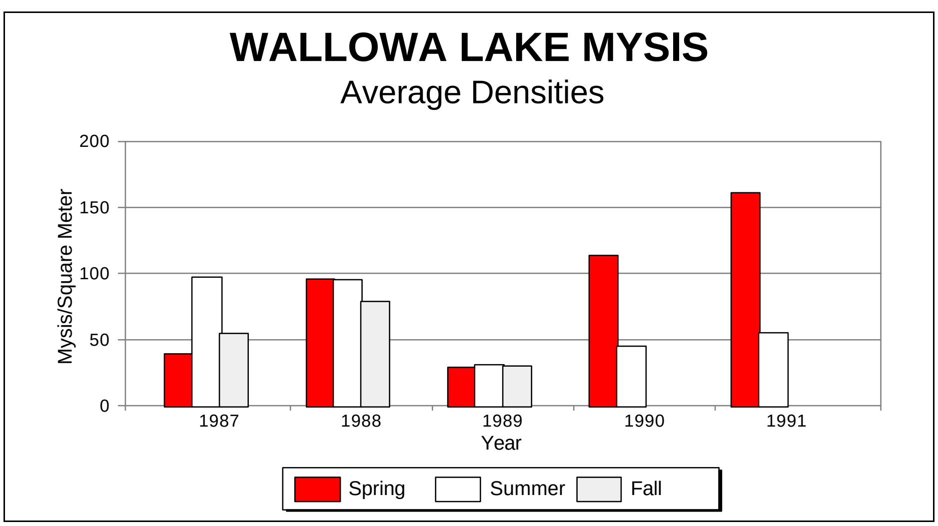


Figure 25. Mean density of Mysis Relicta in Wallowa Lake during spring, summer, and fall of 1987-90 (data collected by ODFW).

We conclude from these data that the zooplankton community in Wallowa Lake has undergone change that is likely to reduce the lake's production of age 0+ kokanee or sockeye. The full effect of this change is still unclear and can only be determined from continued monitoring. Analysis of kokanee stomach contents since 1987 do not clarify the situation (Table 10). Stomachs were sampled over an unspecified period from angler-caught fish, and only the frequency of occurrence of selected items was determined. Ironically, the proportion of kokanee stomachs in which cladocerans were found increased from 1988 to 1990. Copepods, specifically Diaptomous, were found in most stomachs in all years. Aquatic insects were found in 94.6% of the stomachs in 1990, up from 56.6% in 1988. We speculate that the increased occurrence of aquatic insects may reflect decreased availability of preferred zooplankton. Again, definitive answers will require additional monitoring.

Table 10. Contents of stomachs from kokanee caught by anglers at Wallowa Lake during 1987-89 (ODFW data).

		Number (%) of stomachs containing food type				
Year	**# Stomachs Examined**	**Mysis**	**Copepods**	**Cladocerans**	**Aquatic Insects**	**Terrestrial Insects**
1987	150	4 (2.7%)				
1988	159	16 (10.1%)	111 (69.8%)	52 (32.7%)	90 (56.6%)	9 (5.7%)
1989	192	12 (6.3%)	191 (99.5%)	84 (43.2%)	167 (87.0%)	19 (9.9%)
1990	111	2 (1.8%)	103 (92.8%)	98 (88.2%)	105 (94.6%)	14 (12.6%)

Interactions with Existing Fish Species

Lake Trout As discussed in the section on **Abundance and Catch**, it appears that stocking of lake trout in Wallowa Lake during 1956-61 may have contributed to the decline of kokanee following the Wallowa River channelization project. The present concern at Wallowa Lake is a potential interaction of kokanee, lake trout, and *M. relicta,* similar to that reported by Bowles et al. (1991) at Priest Lake, Idaho. *M. relicta* became established in Priest Lake in 1970 and abundant in 1972. At that point in time, kokanee harvest began to drop, lake trout harvest increased dramatically, but fish size declined (Bowles et al. 1991).

Angler catch records indicate lake trout are self sustaining in Wallowa Lake only at very low levels. Following the last lake trout stocking in 1961, their abundance in the angler catch dropped to 0 by 1967 and remained there until 1987 when a few lake trout again began appearing in the catch (see Table 2). This reappearance of lake trout is again reminiscent of the events at Priest Lake. There, lake trout were of minor importance and kokanee contributed roughly 95% of the game fish catch in the mid 1950's (Rieman et al. 1979). Lake trout were feeding on kokanee and increasing in abundance when *M. relicta* was introduced in 1965, but kokanee were still being captured at 1.25 fish/hour in 1970. *M. relicta* became abundant in 1972 and the kokanee fishery declined consistently until it hit 0 in 1986 (Mauser et al. 1988). The presence of *M. relicta* provided forage for young lake trout and evidently enhanced their growth and survival (Rieman et al. 1979). Rieman et al. (1979) found Mysids in 67% of the stomachs and kokanee in none of the stomachs of the lake trout under 51 cm FL; however, Mysids were found in only 6% of the stomachs and kokanee in 88% of the stomachs of lake trout greater than 76 cm FL. The recent increases in abundance of Mysids, the reappearance of lake trout in the catch, and the concern about the abundance of kokanee in Wallowa Lake are evidence that the zooplankton community has been in transition. Data for Wallowa Lake are not sufficient to confidently predict the balance that will be reached in the zooplankton and fish communities, but angler catch data for kokanee and lake trout during the 1990's indicate that the spin-off effects from establishment of Mysids are unlikely to include a substantial expansion of the lake trout population.

Kokanee

There are concerns among resource managers that competition between kokanee and sockeye for the same food base and spawning areas would either substantially reduce the kokanee yield or hinder the reestablishment of sockeye. To begin with, we know that kokanee and sockeye coexisted in Wallowa Lake prior to 1900 (Everman and Meek 1897), but we have no estimates of their relative abundance. Both kokanee and sockeye coexist in many lakes today, such as Lake Wenatchee (Mullan 1986) and Babine Lake (Beacham and McDonald 1982). Lake Wenatchee currently supports substantial fisheries for both kokanee and sockeye. According to Mullan (1986), the angler harvest in Lake Wenatchee was last estimated in 1964 at 31,549 kokanee. Estimated harvest peaked at 60,000 kokanee, or 24.5 kokanee/acre, in 1954. This compares to a peak harvest of 49,803 kokanee or 33 kokanee/acre for Wallowa Lake in 1976. Sockeye returns to Lake Wenatchee from the 1952 and 1953 broods (lake rearing during the 954 peak in kokanee harvest) were average; 54,100 and 48,800, respectively (Mullan 1986). These comparisons are especially instructive in light of the similar productivity of the two lakes, as indicated by a mean secchi depth of 20.7 ft in Lake Wenatchee (Mullan 1986) and 20.5 ft in Wallowa Lake (Johnson et al. 1965). Rieman and Meyers (1990) found that secchi depth was strongly related to growth and yield of kokanee.

Differences between years in mean lengths of kokanee spawning above Wallowa Lake indicate that growth is reduced as kokanee abundance increases. Density dependent effects on growth have been widely observed in kokanee and sockeye populations (see Rieman and Meyers 1990 for a review). We examined the influence of population density on length at maturity in Wallowa Lake kokanee by using angler catch per hour during May-June as an index of abundance. Spawners were not sampled during 1952-53 and 1960-65, but gill-net samples were taken in October in those years. In years when data were collected both from spawners in September and gill nets in October, we found a highly significant correlation between the two (Figure 26). We used the regression in Figure 26 to estimate spawner lengths for years when fish were only sampled by gill nets. We found that variation in mean length of spawners between years showed a negative exponential relationship to kokanee catch per hour during May-June (Figure 27). This relationship is similar to that found by Rieman and Meyers (1990) for lengths at age 2+ and 3+ for kokanee in nine lakes and reservoirs in Idaho and Oregon. This finding substantiates that length at maturity, and therefore growth, of kokanee in Wallowa Lake is density dependent. But the question remains, "Would this same relationship be true for sockeye that rear only to age 1 before emigrating?"

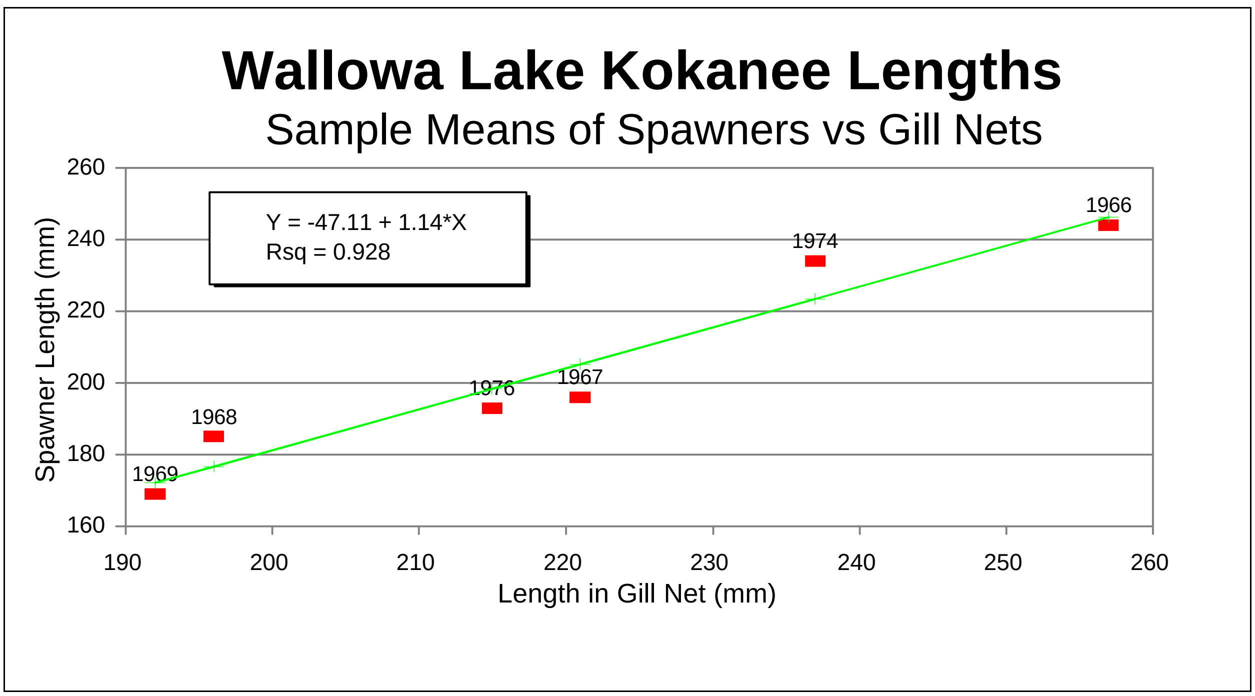


Figure 26. Relationship of length of spawning kokanee in the Wallowa River in late September to the length of kokanee gill netted in the lake in October (data from ODFW).

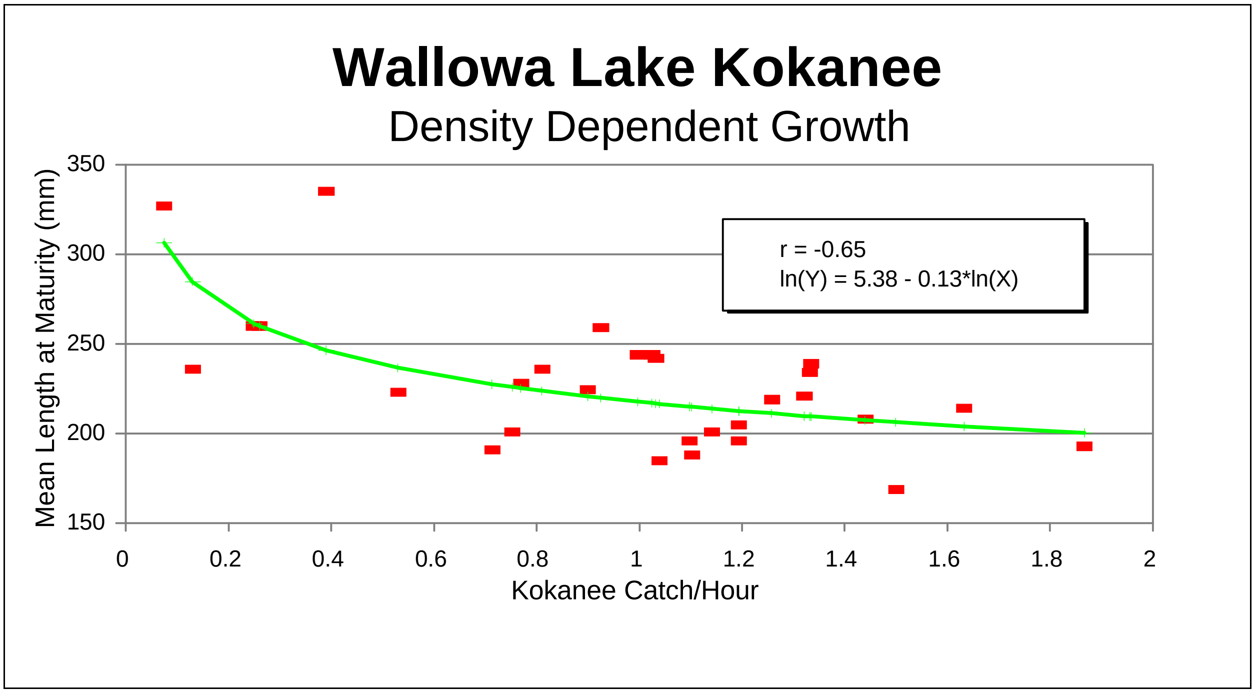
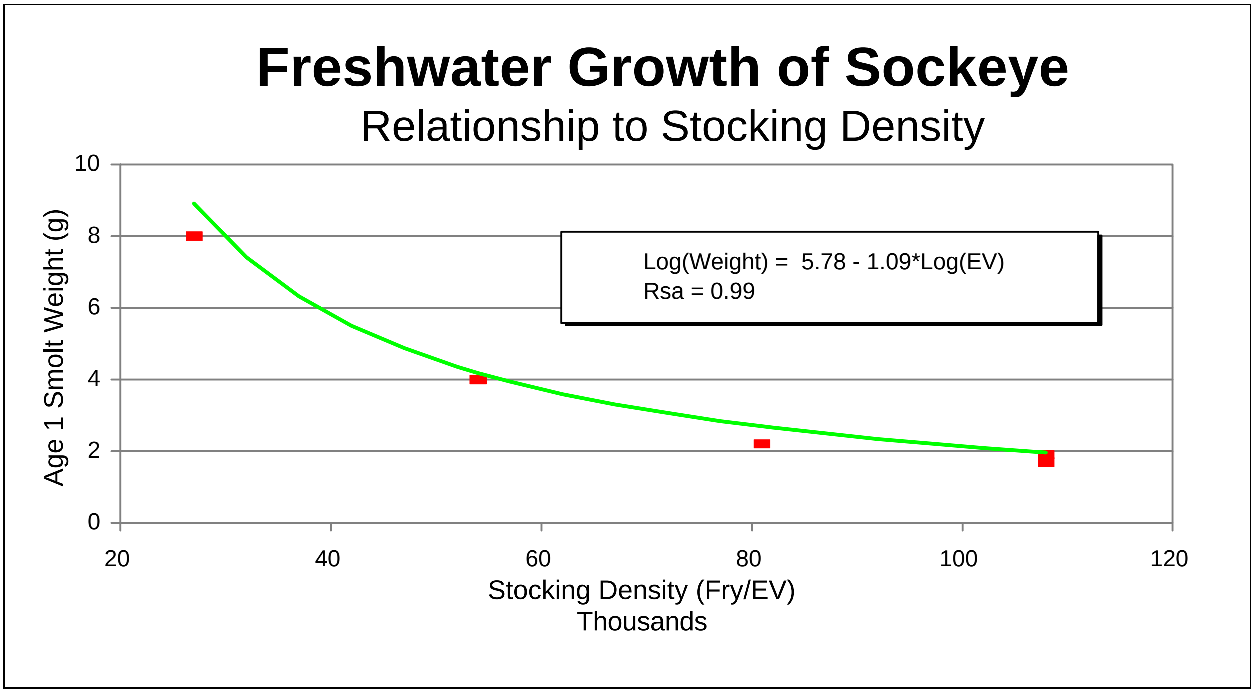


Figure 27. Relationship of mean length at maturity of kokanee to their density in Wallowa Lake, indexed by mean kokanee catch per hour from boats in May-June (data and estimates from ODFW).

Rieman and Meyers (1990) examined data from nine lakes and reservoirs in Idaho and Oregon and found density-dependent growth at age 2+ and 3+, but not at age 1+, even though fish per hectare varied widely. Rieman and Meyers conclude from their analyses that intraspecific competition in kokanee is more important within, rather than among, age classes, because there is a divergence of food habits among age groups (Rieman 1981b). Rieman (1981b) noted greater divergence between ages in diet overlap indices at Coeur d'Alene Lake than at Pend Oreille Lake and hypothesized that food habits diverge more between age groups as competition for food increases. Rieman (1981b) found growth of age 0+ and modal size at age 1+ were positively related to biomass of preferred prey and were not correlated to kokanee density. This dependence on prey density resulted in a slightly positive relationship of length at age 1+ to kokanee density, in contrast to the negative form of this relationship for age 2+ and 3+ kokanee. These findings led Rieman and Meyers (1990) to hypothesize that density dependent control of kokanee populations may be related to reduction of fecundity as growth of age 3+ fish declines with fish density.

In contrast to Rieman and Meyers (1990) findings for kokanee, numerous studies have demonstrated density dependent growth of sockeye at age 0+ and age 1+. Density-dependent growth to age 1+ sockeye smolts was dramatically demonstrated by stocking various densities of sockeye fry into Leisure Lake, Alaska, where a barrier falls prevents access by adult sockeye (Koenings and Burkett 1987). Koenings and Burkett (1987) found that smolt weight showed a negative exponential correlation to stocking density, and freshwater survival was linearly correlated with stocking density (Figure 28). Koenings and Burkett (1987) expressed stocking density as fry per euphotic volume(EV) and defined euphotic volume as 100 m cubed of surface area x euphotic zone depth. Similarly, Burgner (1987) showed the mean weights of age 1 and 2 smolts from both the Wood and Kvichak rivers were inversely related to the density of parent spawners. Goodland et al. (1974) showed an inverse relationship between sockeye smolt size and the density of their parent spawners for several lakes in the Fraser River system. Kyle et al. (1988) found the size of age 1 sockeye smolts from Frazer Lake, Alaska, was negatively correlated with the abundance of their parent spawning run. Kyle et al. (1988) also monitored zooplankton and found a negative logarithmic correlation between the parental escapement and subsequent year seasonal macrozooplankton densities. In other words, feeding on zooplankton by large numbers of juvenile sockeye resulted in reduced abundance of zooplankton, which in turn caused decreased growth of sockeye. Kyle et al. (1988) also found that sockeye selectively fed on larger individuals of Daphnia and Bosmina, such that the mean size of Bosmina in Frazer Lake, during years of extreme sockeye abundance, was reduced to less than the minimum size at which sockeye would eat them.



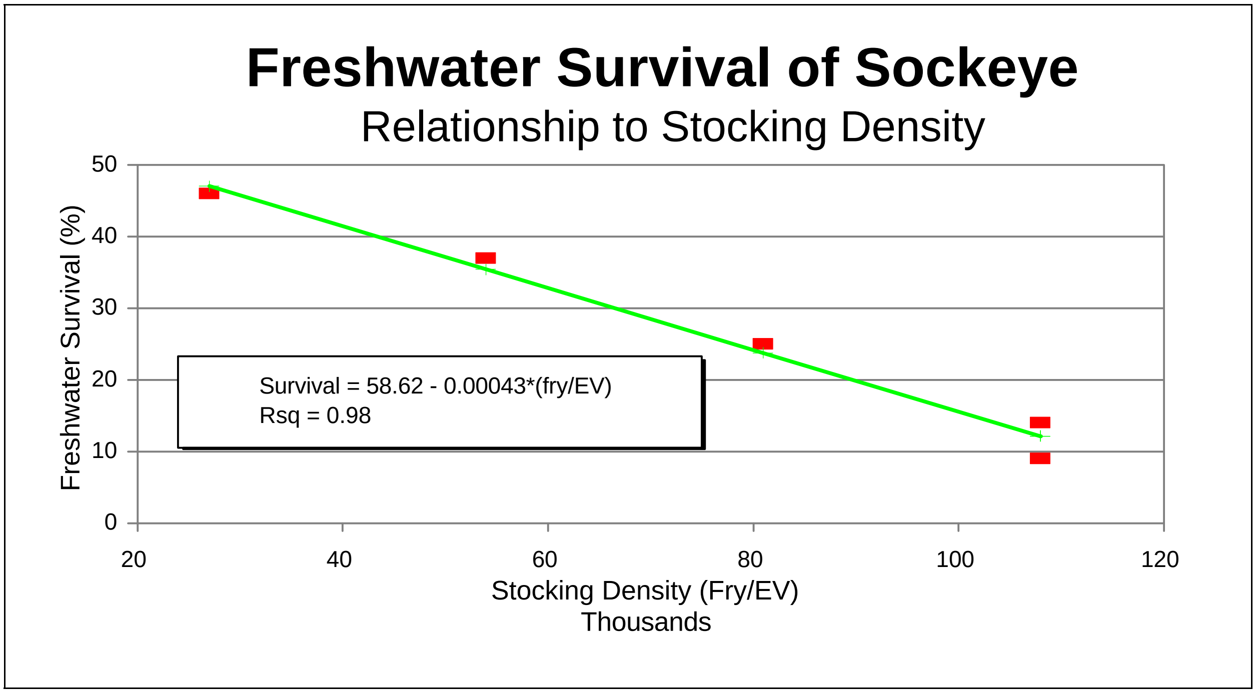


Figure 28. Relationships of freshwater growth and survival of juvenile sockeye to their density in the Nursery Lake (after Koenings and Burkett 1987). Freshwater survival is measured from abundance of fry in the spring to abundance of age 1 smolts the next spring.

If sockeye show density dependence at age 1, why is density-dependent growth among kokanee not apparent until age 2+? An answer can be found from the hypothesis by Rieman and Meyers (1990) that density-dependent control of kokanee populations is ultimately manifested through changes in fecundity. According to the Rieman and Meyer hypothesis, kokanee populations are spawner limited. In keeping with this hypothesis, sockeye populations that are spawner limited also show no indication of density dependent growth at age 1 (Koenings and Burkett 1987). Sockeye in Lake Washington are an excellent example of a population showing no indication of density dependence and 94% of the variation in the abundance of smolts per spawner is accounted for by a negative correlation to peak flow while eggs are in the gravel (Thorne and Ames 1987). The fecundity of an adult sockeye (approximately 3,000 eggs/female historically for Wallowa Lake) is about eight times greater than an adult kokanee (350-400 eggs at 23 cm for Wallowa Lake based on gill net samples in 1973). Thus, adult sockeye can produce many more fry per spawner, and the smolts leave the lake before the density limitation at age 2 and 3 is reached. This in turn, allows greater production of adults, which produce more eggs, and so on, until the rearing capacity of the lake for fry becomes the factor limiting the sockeye population.

The next and most important question is, "What happens when we merge a fecundity-limited kokanee population with a rearing-limited sockeye population?" Obviously, some kind of balance is achieved because the races coexisted in Wallowa Lake. This question has a complex answer, first because of the divergence in food habits between ages, as described by Rieman (1981b) and discussed previously, and second because of potential spatial segregation between sockeye and kokanee. Levy (1987) cites several examples of opposite patterns in vertical diel migrations between kokanee and sockeye. Juvenile sockeye typically migrate vertically toward the surface at night and return to deeper areas during the day. Kokanee in Nicola Lake are shallower by day and deeper by night in summer and fall (Northcote 1967 cited by Levy 1987). In Babine Lake, McDonald (1969) purse seined kokanee in 0-16 m depth during day, indicating a surface orientation during day. Finally, in Pend Orielle Lake, Rieman and Bowler (1980) found kokanee were distributed between 0-20 m during daylight and between 18-27 m during night. These differences in vertical migration may be a genetic adaptation that enhances the ability of kokanee and sockeye to coexist.

The dynamics of these interactions can be modeled, but the foundation for the numerous assumptions required would be weak, and predictions by the model would be of questionable value. However, such a modeling exercise could become valuable if appropriate data on spatial distribution and food habits of kokanee at each age in Wallowa Lake were collected. A simpler approach, and perhaps more accurate, would be to assume that the kokanee-sockeye balance would be similar to that in Lake Wenatchee. This comparison indicates the kokanee population would be only slightly reduced by about 25%. It appears probable from the available data that sockeye would have a slight competitive edge over kokanee. First, the large sockeye could maintain dominance in spawning areas (Foote and Larkin 1988), and their larger sized eggs compared to kokanee would result in slightly larger fry. Foote and Larkin (1988) found that kokanee and sockeye spawning at the same time and location do mate assortively, and that spawners choose mates of similar size and body characteristics. Second, probably a greater advantage to sockeye would result from their need to rear in the lake only until smolting at age 1. Because the preferred size of prey is related to the size of fish, age 0+ sockeye get "first shot", compared to older kokanee, at feeding on the smaller sizes and thus younger individuals of a given prey species. This only turns out to be an advantage if smaller sized prey species are available. Overgrazing by sockeye on zooplankton, such as occurred in Frazer Lake (Kyle et al. 1988), is highly unlikely in Wallowa Lake, because losses of smolts and returning adults as they pass mainstem dams will reduce the smolt-to-adult survival to as little as 1/10 that experienced by Wallowa Lake sockeye before 1900.

The balance of kokanee and sockeye is also likely to depend on the assemblage of zooplankton species in the lake. For example, despite findings by Rieman and Meyers

(1990) that kokanee growth is only density dependent at age 2+ and older, Lindsay and Lewis (1978) found growth of age 0+ kokanee in Odell Lake inversely proportional to the abundance of older age groups. Lindsay and Lewis (1978) also found that the abundance of a year class of kokanee was highly correlated ($R^2 = 0.91$) to the mean density of Cyclops during June-September. Similarly, Rieman (1981b) found that growth of kokanee fry in Pend Orielle Lake was correlated r = 0.92) to Cyclops biomass. These findings are not necessarily contradictory to Rieman and Meyers (1990), but rather may reflect the seasonal availability of zooplankton. In Odell Lake, Cyclops was the only abundant zooplankton during spring to mid summer, so all age classes of kokanee had to feed on Cyclops, but fry switched their consumption to Daphnia when Daphnia became abundant in late summer. Koenings and Burkett (1987) found that sockeye fry in Packers Lake, Alaska, fed selectively on Daphnia and Bosmina and completely ignored the abundant Cyclops. Koenings and Burkett (1987) found that sockeye fry did feed some on Diaptomous, but at a rate substantially less than their proportional availability. In Wallowa Lake, Cyclops is absent and the dominant zooplankton is the larger Diaptomous, especially in the spring and early summer (see Figure 24). The temporal distribution of zooplankton in Wallowa Lake indicates that density-dependence may act in a pattern similar to that in Odell Lake. This conclusion is speculative, and can be tested by studying the size and abundance of zooplankton in Wallowa Lake in combination with the food habits of the kokanee at each age.

Evermann and Meek (1897) reported that the residual population of kokanee in Wallowa Lake were predominately males. Although the sockeye salmon is typically anadromous, there are two forms that remain in fresh water to mature and reproduce; kokanee and the so-called “residual” sockeye (Ricker 1938). The “residual” sockeye are mostly males (Burgner 1991). It is quite likely that residual male sockeye inhabitated Wallowa Lake until the kokanee population declined following the introduction of lake trout in the late-1950's and the channelization of the spawning grounds in 1950.

Managers are concerned that reintroduction of sockeye salmon into Wallowa Lake will result in competition between kokanee and sockeye. Our analysis shows that intraspecific competition may occur between kokanee and sockeye salmon. We found no examples where one race has completely excluded the other, and some examples were both races are abundant. If a high percentage of male sockeye residualize and enter fisheries at Wallowa Lake, the impacts of sockeye reintroduction may have a nil effect on resident fisheries in Wallowa Lake.

Rainbow trout

Interactions of rainbow trout and kokanee have been modeled in Lake Washington by Swartzman and Beauchamp (1990) in Lake Washington. Their model was developed to address the concern that introduced rainbow might prey on juvenile sockeye. They concluded that predation by rainbow on sockeye would be negligible, and that predation would strongly depend on the abundance of rainbow and of prey species. Beauchamp (1990) confirmed by field sampling that rainbow <25 cm did not eat fish in Lake Washington. Further, Beauchamp (1990) found the diel distributions with respect to depth differed between rainbow >25 cm (which did eat fish) and age 0+ sockeye such that the two were spatially isolated. Beacham and McDonald (1982) found kokanee in Babine Lake were preyed upon by rainbow > 25 cm, and that, during short time periods, up to 30% of the fish eaten by rainbow (70% of their diet was fish) were sockeye. Also of concern, Beauchamp found that the primary diet of rainbow <25 cm during summer and fall was Dapnia. Thus, rainbow under 25 cm would compete with sockeye for the same food base. These data indicate that stocking of rainbow in Wallowa Lake would have a negative, but probably small, impact on sockeye reintroduction.

POTENTIAL DONOR STOCKS

Given that the potential exists for establishment of a self-sustaining population of sockeye in Wallowa Lake, we next must identify potential seed stocks that have the appropriate genetic characteristics. The seed stock chosen may ultimately determine the success or failure of the reintroduction, because sockeye are highly adapted for survival in specific lakes and rivers. Foote et al. (1989) found electrophoretic differences in the genotypes of kokanee and sockeye from the same lake, and yet found that kokanee and sockeye within a lake tended to be more similar than did sockeye populations compared between lakes. Killick and Clemens (1963) demonstrated that sockeye stocks within the Fraser River system are highly differentiated. They found that age 4 spawners were predominant in the upper watershed whereas age 5 spawners were predominant in the lower watershed. They also showed that maturing fish destined for the upper watershed migrated at twice the rate of fish destined for the lower watershed. Within the Fraser system, they showed that Adams River stock entered the Fraser River 2 months later and spawned 2 months later than farther migrating early Stuart stock. The order of river entry time for the various stocks within the Fraser was maintained between years. Killick (1955) found that each sockeye stock in the Fraser River system had a characteristic migration rate that was maintained from the time it entered the river until it reached the nursery lake. Killick also found that time remaining after lake entry until death was less for stocks that migrated shorter distances. Killick concluded that body energy reserves, migration timing, and migration rate were critically linked to enable the fish to arrive at the spawning grounds and spawn at the optimum time.

Several stock characteristics can be identified which will be necessary for sustained survival of a Wallowa Lake population. These characteristics are listed below:

! Adult entry to the Grande Ronde River (662 miles from the ocean) during early July is desirable (see Environment for Upstream Migration)

! Adults must possess the energy reserves and maintain a migration rate necessary for the migration of 794 miles to the lake

! Fish must be resistant to the variety of diseases common in the Columbia River

! Peak spawning time should be near September 15 for spawners in Wallowa River upstream of Wallowa Lake and November 1 for lake spawning (see Figure 12)

The two most obvious stocks for consideration are the two viable stocks in the Columbia Basin, the Wenatchee and Osoyoos stocks. These two lakes represent radically different environments so genetic differences should be expected. Lake Wenatchee is oligotrophic while Osoyoos Lake is eutrophic (Mullan 1986). As a result, the mean length of sockeye smolts from Lake Wenatchee averages about 9cm compared to 11 cm from Lake Osoyoos (Mullan 1986). Utter (1974, as cited by Utter et al. 1980) showed electrophoretically that sockeye populations from the two lakes were genetically distinct. Therefore, the merits of using either stock as a seed for Wallowa Lake should be considered separately.

Run timing of the two stocks has not been differentiated in the Columbia River. Sockeye first appear at McNary Dam (RM 292) in early June and passage peaks in early July. Only the earliest portion of this run will be able to reach the Grande Ronde River before July 10. The Lake Wenatchee run generally reaches the lake (512 miles from the ocean) about August 1 (Allen and Meekin 1973). This migration timing and rate would get these fish to the mouth of the Grande Ronde River (150 miles farther) in August 1. Sockeye generally reach Lake Osoyoos (613 miles from the ocean) in late August to early September (WDF et al. 1989). Thus, Lake Osoyoos sockeye would reach the Grande Ronde River about the first of September. These migration times are later than desirable but may be viable, because river temperatures generally begin declining in late August.

Selection of the earliest sockeye migrants at McNary Dam will also be associated to some degree with earlier spawning. Spawning peaks in mid September for the Lake Wenatchee stock and in mid October for the Lake Osoyoos stock (Gangmark and Fulton 1952). These spawning times are already earlier than the November 1 peak for Wallowa sockeye in 1902 and 1903. However, spawning of Wallowa Lake sockeye may actually have begun earlier than hatchery records indicate. Eyewitness accounts of sockeye spawning in the river above the lake during the late 1800's indicate spawning began in mid September (Bartlett 1948). It is possible that heavy exploitation of sockeye by canneries and seining at the inlet to Wallowa Lake had essentially eliminated river spawning sockeye prior to 1902, such that only lake-shore spawners remained. Lake-shore spawners would be expected to spawn later than river spawners, because of the warmer temperatures in the lake than the Wallowa River entering the lake (see **Hydrological Characteristics, Wallowa Lake**). Kokanee have been observed spawning along the shorelines of Wallowa Lake in November, but their success is unknown. Kokanee which successfully reproduce in the lake spawn in late August through September.

Another potential donor source is Redfish Lake sockeye. Bjornn et al. (1968) concluded this run was derived from kokanee in the lake. The anadromous run of sockeye was completely blocked from entry into Redfish Lake by Sunbeam Dam in the Salmon River during 1912-1934. After Sunbeam Dam was removed, sockeye began gradually reappearing in the lake, culminating in an estimated escapement of 4,361 adults in 1955 (Bjornn et al. 1968). The run is now considered extinct, but Chapman et al. (1990) estimated the kokanee population has continued to produce 10,000 to 40,000 anadromous smolts annually during the 1980's. After extensively reviewing the stocking history of the lake, Chapman et al. (1990) concluded the later spawning time of the native kokanee/sockeye stock (peak in mid October) has kept it genetically isolated, and therefore, similar to the original population. Redfish Lake sockeye had to migrate 897 miles from the ocean and gain 6,500 ft elevation. They began reaching the lake in late July with peak entry between August 4-25 (Bjornn et al. 1968). Thus, these fish would reach the Grande Ronde River (231 miles closer to the ocean) about mid July. Therefore, this stock possesses as close to the correct migration characteristics as we could hope to find. The problem lies in obtaining brood stock, because these fish are presently listed on the Federal Register as an endangered species. An aggressive recovery program is in progress for sockeye from Redfish Lake, and if it is successful, fish from this stock may become available as a brood source in the future.

SIMULATION OF REINTRODUCTION

Simulation of escapement and harvest achieved from various reintroduction strategies should be completed after a donor stock acceptable to co-managers is identified and available. We describe here some of the basic concepts to be used in modeling the production of sockeye smolts, and the harvest of adults, but we leave the remainder of the model development for the time when a brood source becomes available.

Smolt Carrying Capacity

A simple method for estimating lake carrying capacity for sockeye smolts has been recently developed by Koenings and Burkett (1987). Koenings and Burkett (1987) examined the yield of sockeye smolts from a number of oligotrophic lakes in Alaska and found that, in lakes where growth showed evidence of density dependence, the numbers and biomass of smolts produced was highly correlated ($P<0.005$) to euphotic volume (EV), an index of areal rates of photosynthesis. They defined EV as the surface area times the euphotic zone depth (EZD), where the EZD is the depth to which 1% of the subsurface PAR [photosynthetically active radiation (400-700 mm)] penetrates. They further defined one unit of EV as 100 m cubed. Koenings and Burkett (1987) present the following set of regression that can be used to estimate the carrying capacity of a lake:

1. Log(Smolt weight) = 5.78 - 1.09*log(Smolts/EV) $R^2 = 0.99$

2. FW survival (%) = 1.89 + 51.86*Log(Smolt weight) $R^2 = 0.92$
3. Smolt No. = -42,021 + 23,010*EV $R^2 = 0.97$
4. Log(Smolt length = 1.71 + 0.31*Log(Smolt weight) $R^2 = 0.99$
5. Log(Ocean survival) = -2.647 + 0.035*(Smolt length) $R^2 = 0.36$
6. Adult Production = -95,000 + 2,498*(EV) $R^2 = 0.95$

The fit of observed adult production to relationship 6 is shown in Figure 29. In these equations weight is measured in grams, freshwater survival was the percent survival from fry stocked in the spring to age 1 smolts, ocean survival was the number of fish caught and escaping expressed as a percentage of smolts, and adult production was catch plus escapement of fish. The first four regressions can be applied to Wallowa Lake, but must be used with modifying relationships to account for competition from kokanee and Mysis. Kokanee can be included (approximately) in the regression accounting for smolt numbers by converting it to smolt biomass, and adding kokanee as a part of that biomass. This assumes that production of age 1+ and older kokanee is related to EV in the same way as sockeye fry. This assumption is reasonable, because kokanee of all ages feed predominantly on zooplankton, which in turn are dependent on phytoplankton and finally primary productivity. EV was used in these predictive regressions by Koenings and Burkett (1987) specifically because they found it was highly correlated to primary production in the lakes studied (Figure 30).

Harvest

Harvest within the Grande Ronde Basin will be modeled as a quota or harvest rate set annually by fishery managers. Prospects for harvest are meager, since the mortality from passage at dams, both up and down stream, is the equivalent of a 66% harvest rate. Net harvest of sockeye in the Columbia River (commercial and Indian) averaged 27% in 1988 and 25% in 1989 based on CWT recoveries of sockeye presented by Carlson et al. (1989). Ocean harvest of Columbia River sockeye is nil (Carlson et al. 1989). The influence of these factors alone on survival will probably result in a population that fluctuates, at best, around the replacement level and produces a harvestable surplus only in years with favorable environmental conditions. This is presently the case with sockeye returning to Lake Wenatchee where anglers harvest about 10% of the run in high escapement years (Mullan 1986).

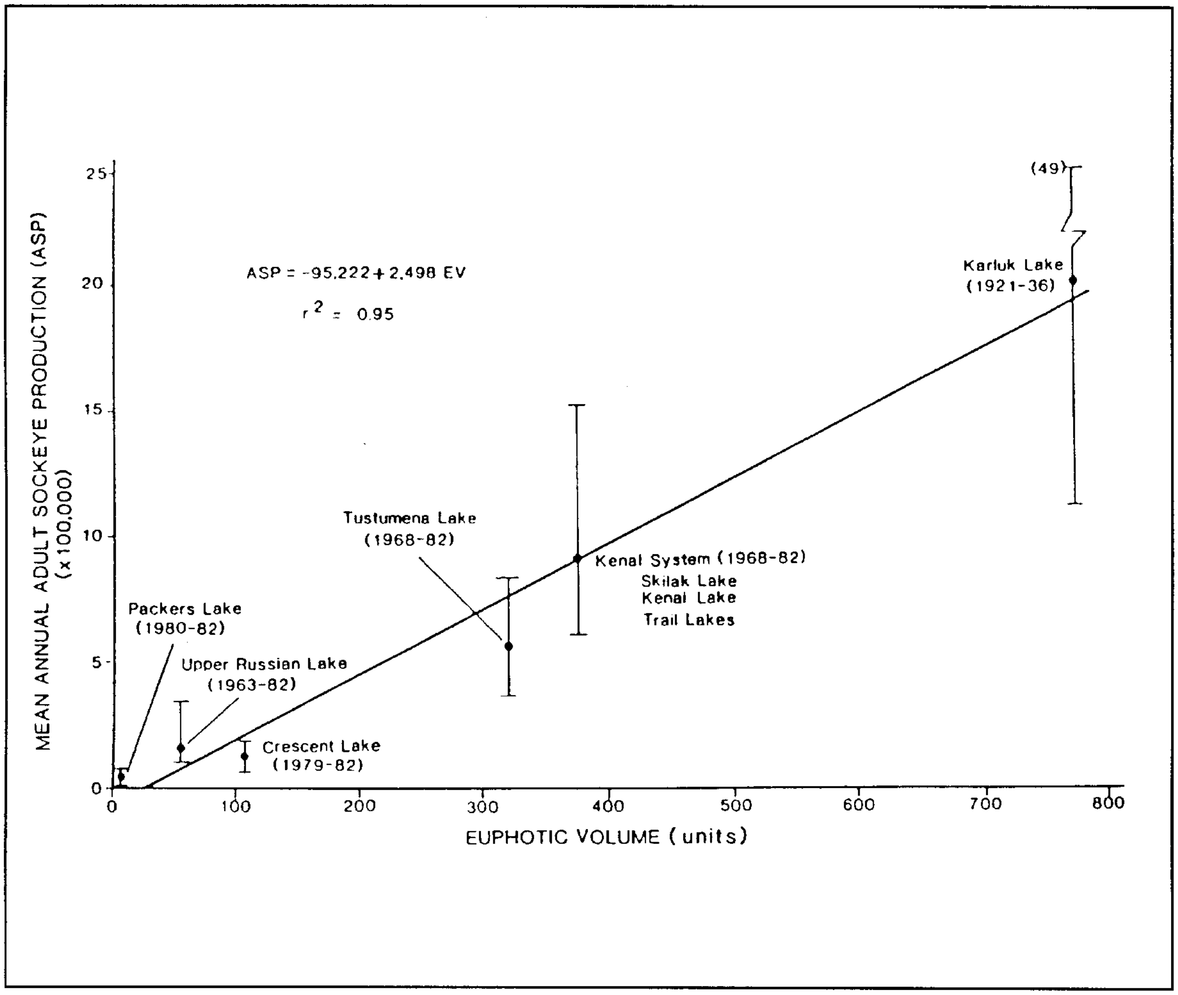


Figure 29. Empirical relationship between total adult sockeye production and the trophogenic zone (units of euphotic volume) for six Alaskan nursery lakes (from Koenings and Burkett 1987).

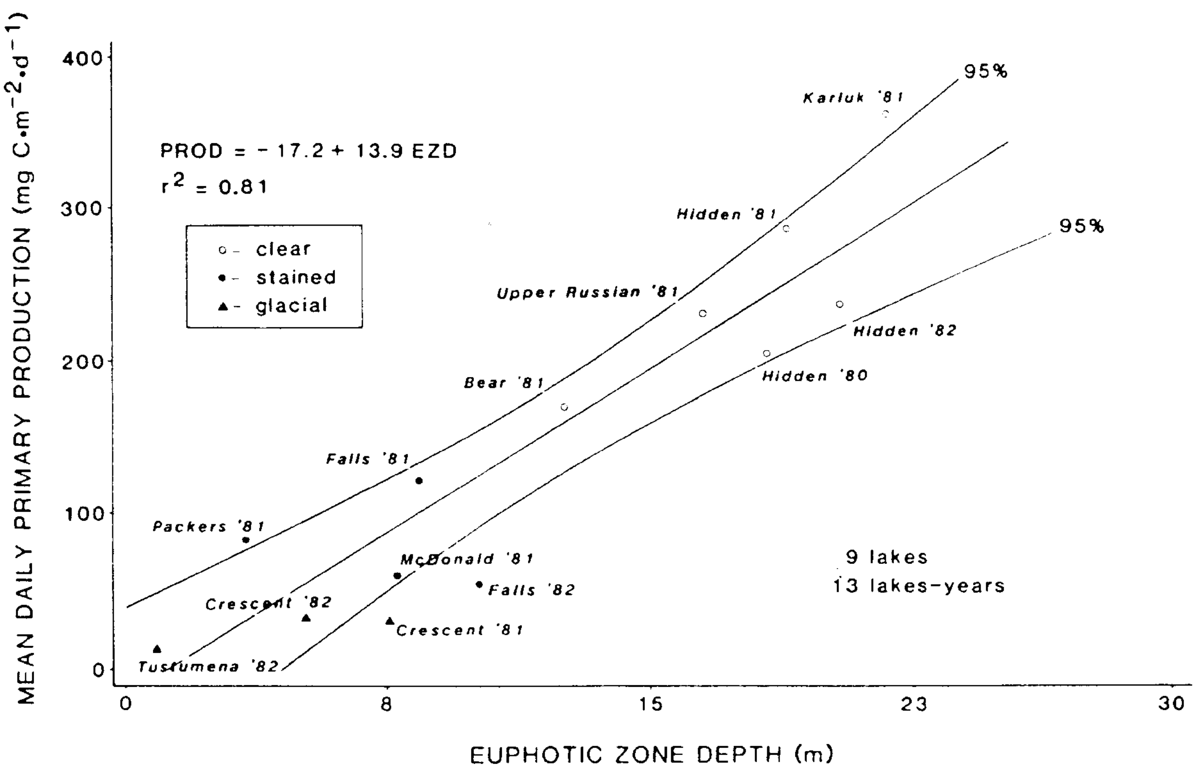


Figure 30. Relationship of observed mean daily primary production and euphotic zone depth from May-October in nine Alaska sockeye nursery lakes (from Koenings and Burkett 1987).

SUMMARY

Classification of Snake River sockeye salmon as Endangered under the Endangered Species Act of 1973 restricts options for selecting a donor sockeye salmon stock for Wallowa Lake. While other stocks may be more suited to conditions facing Wallowa Lake sockeye salmon, we suspect that the Red Fish Lake sockeye salmon may be the only stock meeting criteria outlined in administrative rules governing outplanting animals listed as Endangered under the Endangered Species Act. Availability of the Red Fish Lake sockeye salmon stock is uncertain, and priority for the use of this stock as a donor stock has not be determined. However, planning for the reintroduction of sockeye salmon into Wallowa Lake should proceed. The best way to achieve planning objectives is to set goals. For the purpose of planning, we suggest that the Red Fish Lake sockeye salmon stock will be available for out planting into Wallowa Lake in the year 2007.

We have examined historic and present conditions affecting sockeye salmon in the Grande Ronde Basin. We determined that over-harvest and mis-guided hatchery practices in the early 1900's were major factors causing the extirpation of sockeye salmon in Wallowa Lake. We have determined that the reintroduction of sockeye salmon into Wallowa Lake is feasible, but there are many obstacles, biological and physical, to overcome. Fixing many of the obstacles will be expensive. We present a summary of these obstacles as they affect each life history phase of the sockeye salmon:

<u>Adult migration:</u>

Near lethal water temperatures in lower reaches of the Grande Ronde River during the adult migration period, dewatering of the Wallowa River directly below Wallowa Lake during summer months, and the Wallowa Lake dam pose barriers to adult sockeye salmon migration. Each of these obstacles could prevent re-establishment of sockeye in Wallowa Lake, but each obstacle can be resolved in time. Once a brood source becomes available to initiate reintroduction, adult passage issues can be addressed during a several year period that adult sockeye are trapped at Lower Granite Dam and transported to Wallowa Lake. The feasibility of trapping and transporting adult sockeye salmon to Wallowa Lake needs further analysis.

Spawning:

Channelization of the Wallowa River upstream of Wallowa Lake has changed the natural condition of sockeye salmon spawning areas. We suggest that an inventory be made to determine condition and size of areas suitable for sockeye salmon spawning. If spawning areas are limited, and we suspect they are, we suggest that spawning channels constructed for kokanee in the 1950's be activated for sockeye salmon spawning. Fluctuation of the lake level may also affect historic sockeye salmon spawning areas. We suggest that lake shore spawning areas be measured and evaluated under present conditions for their potential for sockeye salmon spawning.

Egg incubation:

Sockeye eggs spawned in the West Fork of the Wallowa River above the lake may be influenced by water releases from a small diversion dam operated by Pacific Power. License requirements prevent flow adjustments from the dam during the kokanee spawning period. The license should be modified to protect sockeye salmon eggs during their incubation period.

Fry and Parr rearing:

Competition between kokanee, lake trout, opossum shrimp *(Mysis relicta),* and sockeye salmon has been identified as a potential problem at Wallowa Lake. Surveys initiated in 1987 to examine production of opossum shrimp and the affect opossum shrimp on plankton production have been discontinued at Wallowa Lake. We recommend that these studies be initiated again with emphasis directed toward kokanee/lake trout, opossum shrimp inter-relationships. The studies should be designed to determine the production potential of kokanee and sockeye salmon in Wallowa Lake.

Smolt migration:

Out migration of sockeye salmon past Wallowa Lake Dam and past unscreened irrigation canals has been identified as a concern. It will be necessary to design and evaluate methods for passing smolts safely by Wallowa Lake Dam and unscreened irrigation canals directly downstream of Wallowa Lake.

Smolt passage in the Snake and Columbia River migration corridor is presently being addressed. We suggest that all sockeye salmon smolt produced in Wallowa Lake be marked to monitor their downstream survival and aide in the collection of adults on their return passing Lower Granite Dam. Collection of smolts for marking could be achieved as they pass Wallowa Lake Dam or at newly screened diversion canals directly downstream of Wallowa Lake.

Supplementation:

Re-establishment of sockeye salmon in Wallowa Lake will require development of a hatchery supplementation program. If re-establishment is pursued, we recommend that a hatchery program be developed early in the planning process. The program should include consideration of the potential for production and the development of fisheries. Reintroduction of sockeye salmon into Wallowa Lake poses a pathogen and genetic risk to the resident kokanee population. An analysis of this risk should be conducted with any donor stock considered.

THE FEASIBILITY OF REINTRODUCING COHO SALMON INTO THE GRANDE RONDE RIVER

BIOLOGICAL BACKGROUND

Coho salmon, *Oncorhynchus kisutch*, generally spawn in creeks and small rivers from October through April, depending on the stream and their genetic makeup. Fry emerge from the redd in spring and rear in streams or lakes for 1 year. Preferred rearing habitat is pools or lakes. Smolts typically migrate to sea during late April to early June. Coho return to spawn after two summers at sea, hence, they have a 3-year generation time. Some precocious males, termed "jacks," return to spawn after one summer at sea.

Coho are a highly sought sport and commercial fish. They are subjected to intense sport and commercial harvest in the ocean and in the Columbia River. Males that mature as jacks escape most ocean harvest and are caught by anglers in the river, but generally not in the commercial nets. Coho are a popular sport fish in the tributaries of the Columbia River where they return to spawn.

HISTORICAL ABUNDANCE AND DECLINE

Prior to 1900, coho were known to have spawned in many parts of the Grande Ronde Basin. The first measure of abundance comes from the Grande Ronde Hatchery, operated by the state of Oregon, near Troy where a fish rack was placed across the entire Grande Ronde River 2,000 ft above the mouth of the Wenaha and a second rack was placed across the Wenaha River near its mouth in late August 1901 (Van Dusen 1903). Coho began showing up September 14, and by the time spawning operations were terminated due to cold weather, 2,511 females had been spawned (Appendix 10). The eggs taken from these fish were planted back in the river as eggs or fry. The hatchery operated again in 1902, but coho were not spawned, presumably because the hatchery capacity was exceeded with earlier-arriving sockeye and chinook spawn. In 1903, the rack across the Grande Ronde was removed and placed in the Wallowa River 1.5 miles below Minam and the rack in the Wenaha was moved "a couple of miles" up the Wenaha (Van Dusen 1905). Again, only sockeye and chinook eggs were taken at the Wallowa River location, but chinook and 483 coho were spawned at the Wenaha location. The coho eggs taken on the Wenaha were reported as sockeye, but the location and the reported 3,600 eggs/female indicate the fish were coho. The Wenaha station was abandoned after 1903 and the Wallowa River station was not operated in 1904 due to lack of funding. The rack across the Wallowa at Minam was again operated in 1905 and the Master Fish Warden reports, "By leaving our racks in late this season we found that a late run of Silversides came along during the month of November, but before they were ready to spawn the weather turned severely cold and the ice came down the river in such quantities that we were compelled to take our racks out of the river and let the fish go,"(Van Dusen 1907). The runs were dramatically less in 1906 and 1907 when only 188 and 105 female coho were spawned at the Wallowa station (306 males also reported taken in 1907 [McCallister 1909]). By 1909, when no coho arrived at the hatchery, the Master Fish Warden reports, "For several years past, the salmon that were formerly found in the Wallowa River in such large quantities have not been in evidence," (McCallister 1909). Any coho returning to the Wallowa River above Minam would surely have been taken at the hatchery, because a 14 ft high dam had been constructed on the Wallowa River 3 miles below Minam (see Figure 11) and the hatchery moved below it in 1906 (McCallister 1909). Thus, within one coho generation of hatchery operations, coho returning to the Minam and Wallowa rivers above their confluence had been eliminated.

However, coho must have been spawning successfully below the dam, because in 1912, the Master Fish Warden reported, "the Silversides came up in great numbers, and, although it was not the intention of the department to handle any spawn of this specie at this station this season..... we allowed him to take 4,227,000 eggs," (Clanton 1913). Unfortunately, the state transferred these eggs out of the basin; "As the funds in District No. 1 are limited, I think it advisable to transfer the most of these eggs to the different coast hatcheries where the take of this variety of spawn was short this season," (Clanton 1913). No further accounts of spawning coho at Wallowa River Hatchery are reported in the annual reports of the Master Fish Warden of Oregon or the Oregon Fish Commission.

Several important points can be derived from these early accounts of coho:

❶ Coho spawned at least in the Wenaha River and in the Wallowa Basin above the hatchery site below Minam.

❷ Peak escapement into the Grande Ronde was at least 5,000 fish (assuming 50% males). An additional portion of the run would have been harvested in the ocean and Columbia River.

❸ Coho native to the Wallowa Basin above the hatchery dam were eliminated by 1912. The hatchery dam remained until 1924 (see **Sockeye, Historic Abundance and Decline**).

❹ Coho arrived in the Grande Ronde River beginning in mid September. Spawning peaked about November 1 and again about December 1.

Accounts of coho distribution and abundance in the Grande Ronde Basin other than these early attempts at culture are sparse. Parkhurst (1950) surveyed the Grande Ronde Basin during the 1940's and provides some first and second hand reports of where coho spawned in the basin. On October 10, 1940, Parkhurst observed coho spawning in the lower Grande Ronde River, somewhere below Rondowa. Parkhurst also reported that a small run of coho still ascended the Wenaha River, and that the Minam River formerly had a good run of coho. Thompson and Haas (1960) surveyed the Grande Ronde Basin in the late 1950's and observed coho spawning in the lower 5 miles of the Lostine River and in the Wallowa River near Joseph. Thompson and Haas (1960) also comment that Catherine Creek once supported more coho than chinook.

Despite the fact that coho were blocked from entering the Wallowa River above Minam 1905-1924, many were observed spawning in the upper Wallowa Basin during 1966-1977. Distribution and abundance of coho spawners has been surveyed annually by ODFW in the Wallowa River Basin since 1966. Spawners were generally counted once each season in late October or early November in the Wallowa River near Joseph, Prairie Creek, Spring Creek, and the Lostine River near Lostine. Most spawners were observed in the Wallowa River and coho were observed only occasionally in the other streams (Table 11). Spawner counts in the Wallowa River exceeded 40 fish in only 4 years and dropped to zero by 1977 (Figure 31).

Table 11. Counts of spawning coho in the Wallowa River Basin, 1966-81 (data from ODFW, Enterprise).

		Prairie Creek			
Year	**Wallowa R.**	**Hays Fk**	**Pratt Fk**	**Spring Cr**	**Lostine R.**
1957	20	--	--	0	--
1959	18	--	--	2	--
1966	8	0	4	2	15
1967	96	7	7	7	0
1968	18	2	0	3	0
1969	19	0	0	0	0
1970	85	1	1	0	1
1971	114	0	0	1	1
1972	12	0	0	1	0
1973	24	1	0	2	0
1974	7	0	0	0	0
1975	10	0	0		0
1976	54	0	0	2	0
1977	0	0	0	0	
1978	0	0		0	0
1979	2	0		0	
1980	0	0		0	0
1981	0	0		0	

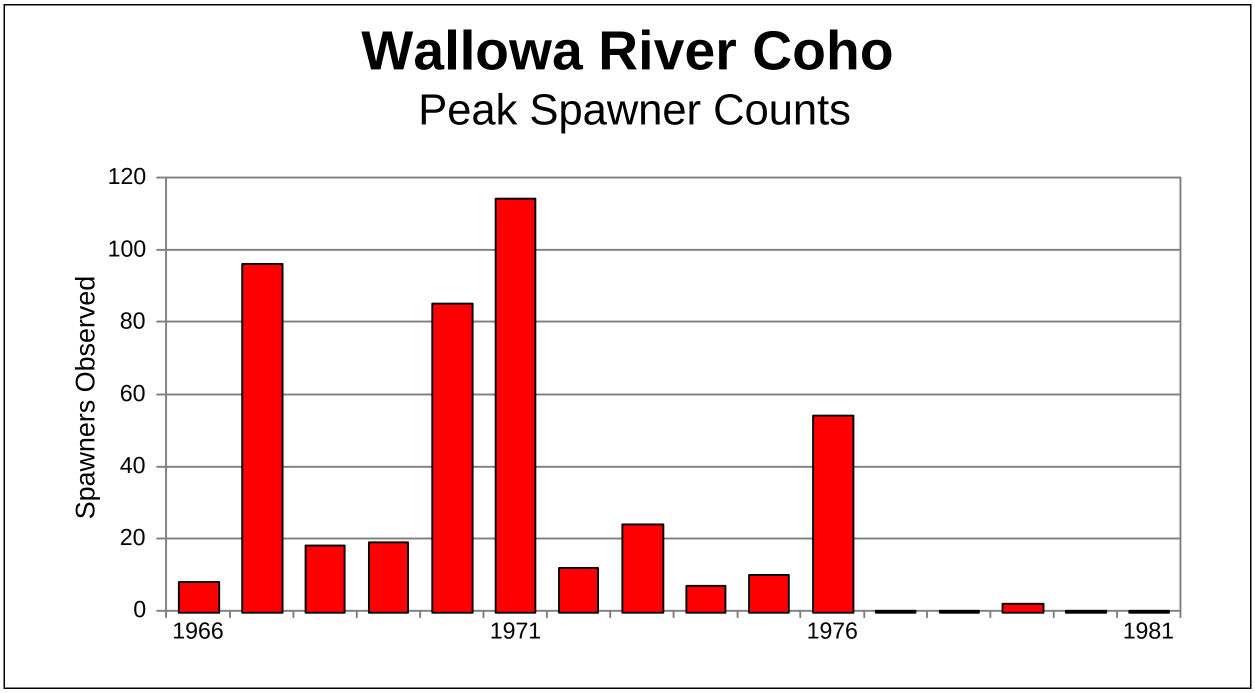


Figure 31. Peak counts of coho spawning in the Wallowa River near Enterprise, 1966-81 (Data from ODFW, Enterprise).

Distribution and abundance of coho since 1960 can also be discerned from catches of juvenile coho in trap boxes at irrigation diversions protected with rotary screens. Juvenile coho were captured regularly in these traps on the Wallowa River, the Lostine River, Hurricane Creek and Bear Creek (Table 12). Again juveniles were most abundant in the Wallowa River, followed by the Lostine River. The number of juvenile coho recovered in traps has been essentially 0 since 1979 (Table 12). Trap box catches indicate that coho abundance was also low prior to 1966 (Figure 32). We found that the number of juvenile coho captured in trap boxes was correlated ($r = 0.58$) to the abundance of spawning coho counted 2 years later (Figure 33). It is likely that most of the juveniles and adults observed in the Wallowa Basin during 1966-77 resulted from hatchery coho eggs planted in the experimental Spring Creek Incubation Channel during 1964-68 and 900 adult hatchery coho released in the basin in 1964. This will be discussed further in the section on Hatchery Influences.

Table 12. Juvenile coho captured in trap boxes associated with screened diversions in the Wallowa River Basin, 1964-1990 (data from ODFW, Enterprise).

Year	Lostine River	Wallowa River	Hurricane Creek	Bear Creek	Total
1961	91	303	N/A	2	395
1962	3	485	N/A	5	493
1963	600	2,146	287	0	3,033
1964	1,236	279	168	10	1,693
1965	N/A	N/A	N/A	N/A	3,498
1966	109	8,944	261	10	9,324
1967	145	3,591	335	51	4,122
1968	4,196	10,543	657	68	15,464
1969	2,075	2,240	370	623	5,308
1970	278	4,317	579	181	5,355
1971	365	1,778	256	16	2,415
1972	484	6,599	315	45	7,443
1973	4,535	12,191	326	227	17,279
1974	537	1,848	90	262	2,737
1975	1,173	2,163	0	81	3,417
1976	450	1,047	0	300	1,797
1977	466	4,867	N/A	547	5,880
1978	19	2,231	N/A	42	2,292
1979	0	18	N/A	4	22
1980	2	0	N/A	0	2
1981	0	5	N/A	0	5
1982	11	3	N/A	0	14
1983	0	1	N/A	0	1
1984	6	0	N/A	0	6
1985	94	1	N/A	--	95
1986	0	5	N/A	32	37
1987	0	3	N/A	0	3
1988	0	0	N/A	0	0

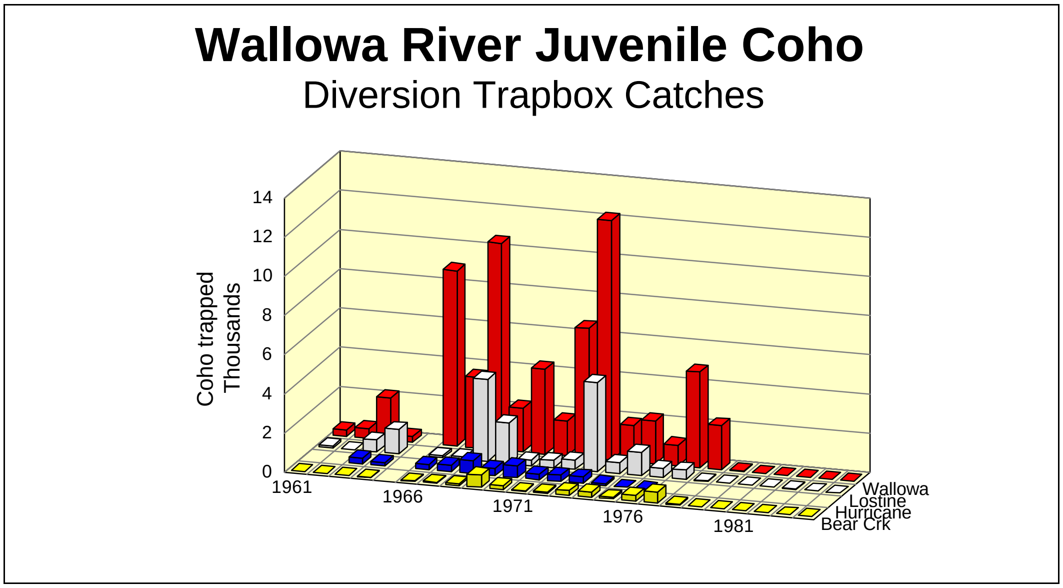


Figure 32. Annual catches of juvenile coho in trap boxes at screened irrigation diversions on four streams in the Wallowa River Basin, 1961-84 (data from ODFW, Enterprise).

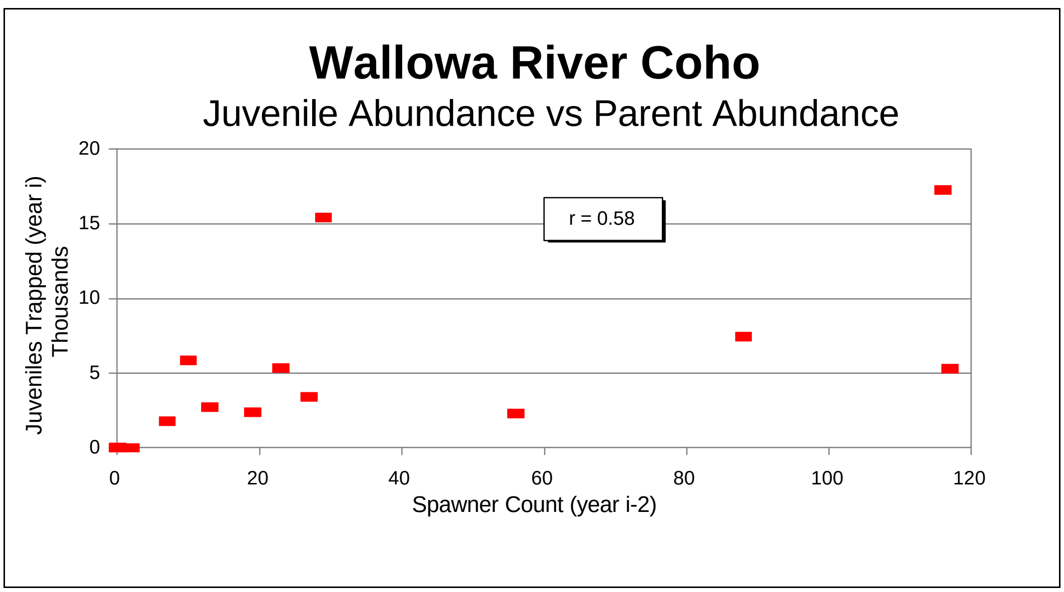
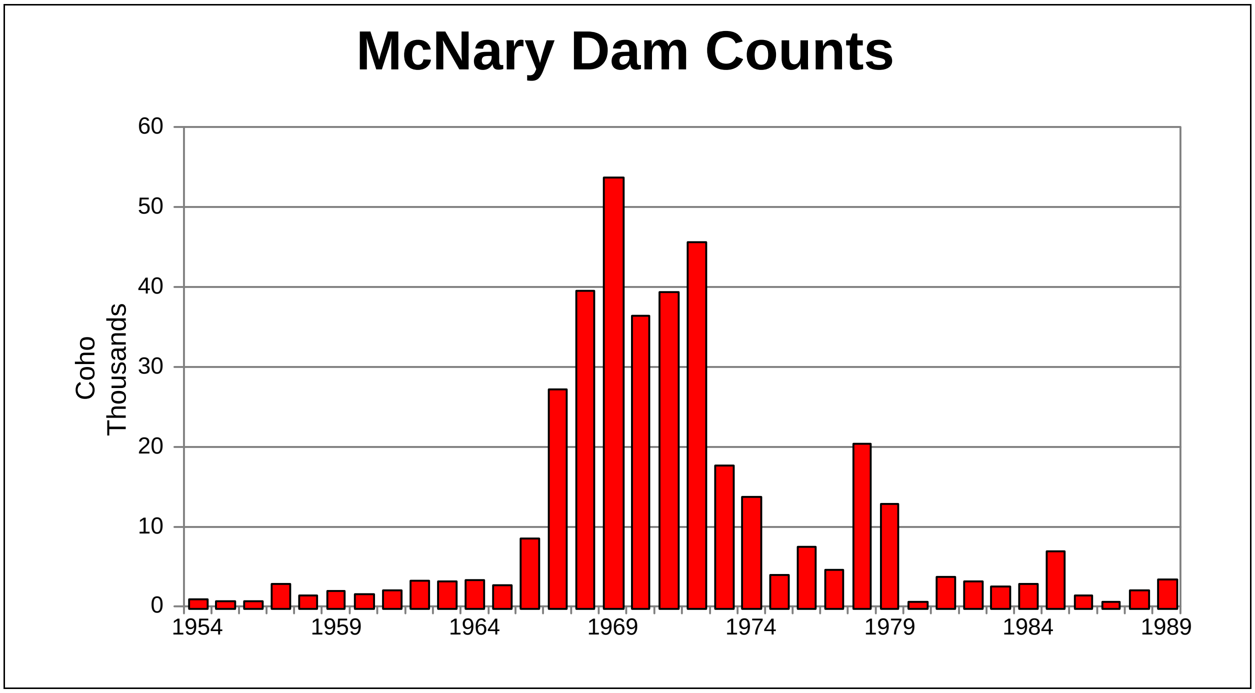


Figure 33. Relationship of juvenile coho catches in trap boxes at screened irrigation diversions, 1968-1983, and peak counts of spawners two years before (data from ODFW, Enterprise).

Counts of coho passing Bonneville and McNary Dams indicate Grande Ronde coho must have been reduced to remnant levels prior to 1950. Only 790 coho were counted over Bonneville Dam in 1945 and fewer than 1,000 coho were counted over McNary Dam during 1954-56, its first 3 years of operation (Figure 34). The sharp increase in coho passing Columbia Dams in the mid 1960's is a reflection of hatchery programs. Counts of coho at Ice Harbor Dam, near the mouth of the Snake River, began in 1962 and show a similar pattern to that at McNary (Figure 35). Thus, coho counts at the mainstem dam also lead to the conclusion that coho in the Grande Ronde River during 1966-77 were the product of hatchery programs.

It is necessary to review data on coho harvest in the Columbia River to understand when the coho declined and why. We have already seen that misguided hatchery practices drastically reduced the production of coho in the Grande Ronde Basin, particularly the Wenaha and Wallowa Rivers in the early 1900's. Prior to 1938 when Bonneville Dam was completed, commercial harvest is the only available index of coho abundance. The ocean troll harvest did not begin until about 1912 (Mullen 1981), so nearly all harvest was in-river. Landings in the Columbia River should reflect abundance accurately because commercial harvest was relatively unrestricted prior to 1938 (Johnson et al. 1948). Commercial harvest of coho in the Columbia River peaked in 1895 and again in 1925 at over 850,000 fish, and had declined sharply between 1925 and 1938 to 257,000 when counts began at Bonneville Dam (Mullen 1981). Catch continued to decline until it hit bottom about 1960 (Figure 36), before major hatchery programs took effect. The highly restricted commercial fisheries in the Columbia River during 1970-90 have harvested about 50% of the coho entering the river (PMFC 1990), so the unrestricted harvest rate at the turn of the century must have exceeded 75%. This would mean that the run of 5,000 coho that reached the Grande Ronde River in 1901 represented at least 20,000 fish entering the Columbia River. Thus, the decline of coho in the Columbia cannot be assigned to the effects of dams, but apparently resulted from overharvest, misguided hatchery operations, unscreened water diversions, and other environmental degradation.



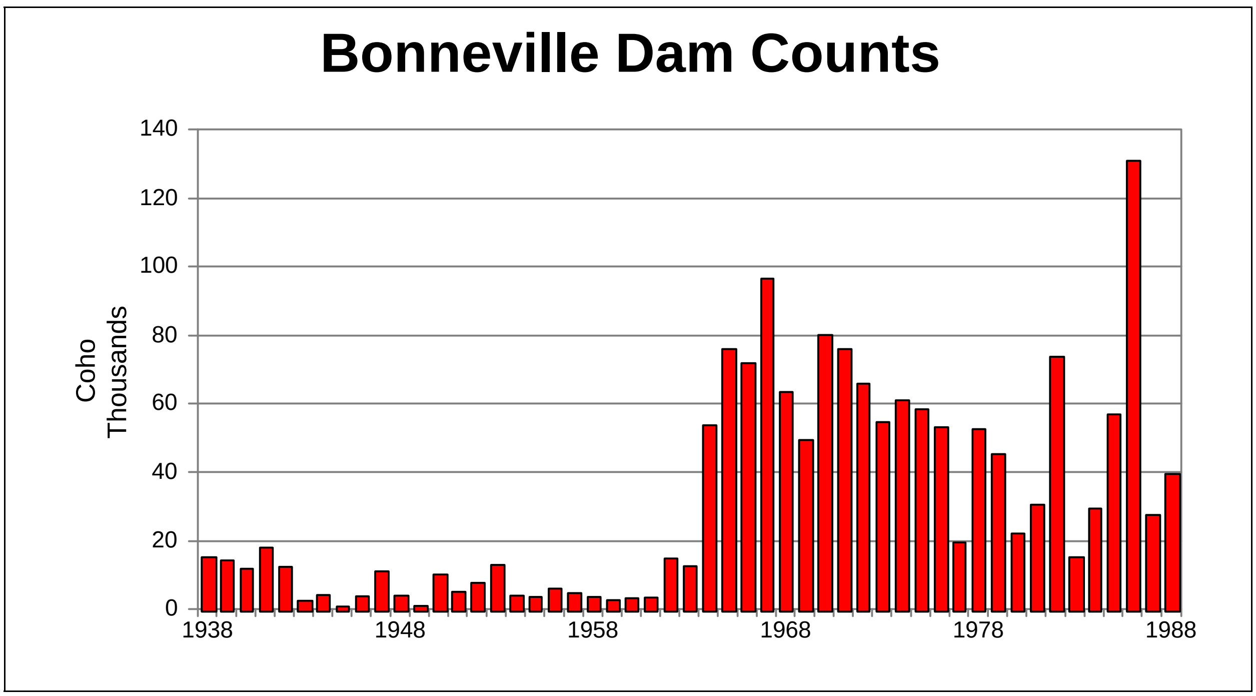


Figure 34. Annual counts of maturing coho passing Bonneville and McNary dams (USACE 1990).

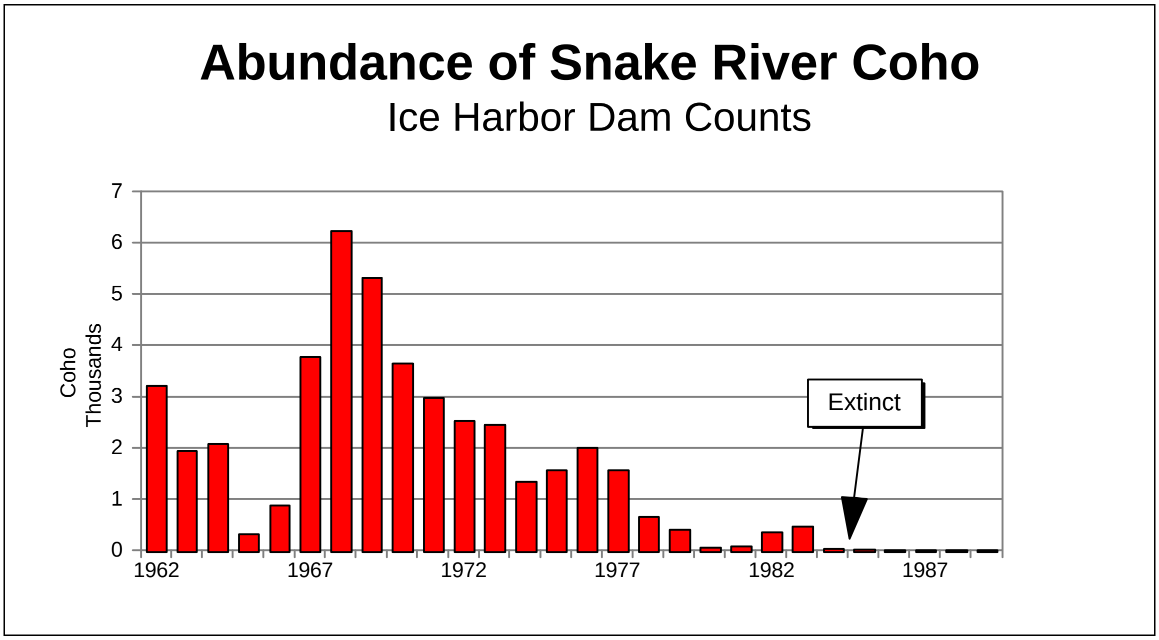


Figure 35. Abundance of maturing coho entering the Snake River as they passed Ice Harbor Dam, 1962-1989 (USACE 1990).

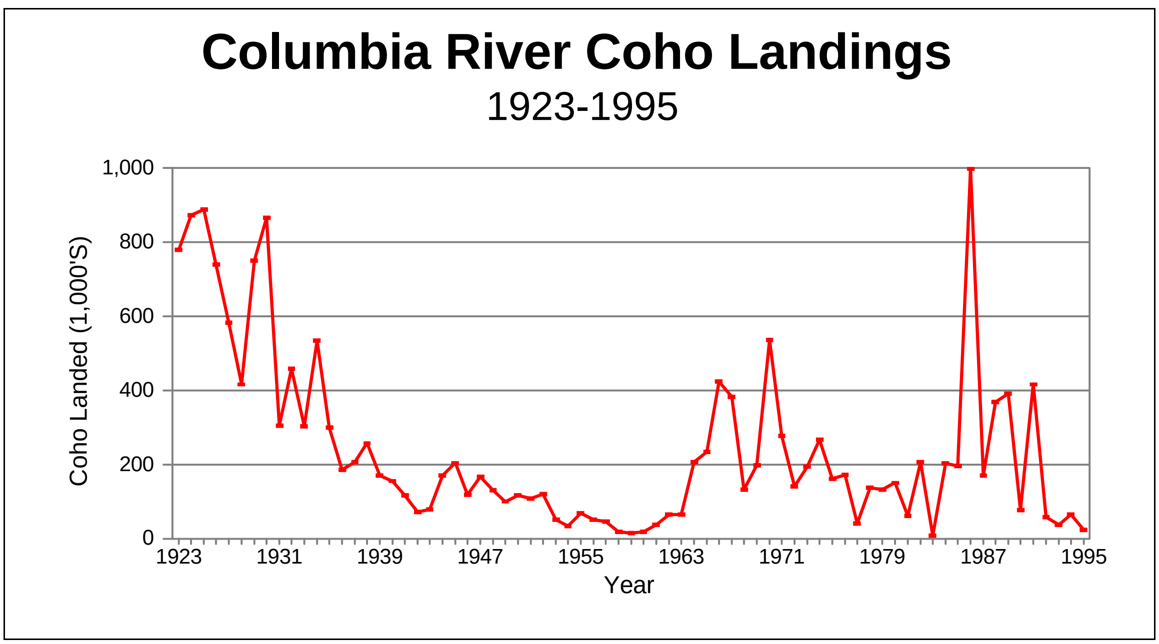


Figure 36. Pounds (round) of coho salmon landed on the Columbia River, 1923-1960 (from Mullen 1981).

HATCHERY INFLUENCES

In addition to the hatchery operations already described at the beginning of the century, hatchery coho were also stocked in the Wallowa River from outside sources during 1924-1937 (Table 13). All transfers into the basin were transferred as eggs to Wallowa Hatchery at Enterprise where they were reared for release as fingerlings in the Wallowa River. One million fry were released in 1924 and 1.3 million fingerlings were released in 1925. The source of these eggs was not recorded. Eggs were also reported as being taken at Wallowa Hatchery in intermittent years. Don Davis, land owner downstream of the Wallowa Hatchery in Enterprise, reported that a weir was constructed on his property to capture adult salmon for the Wallowa Hatchery. Species collected and period of weir operation was never determined. It is likely that eggs taken at this weir were transferred to the Wallowa Hatchery and were reported under "eggs taken" in some annual reports. It is also likely that these plantings ultimately gave rise to the spawning coho observed in 1940 by Parkhurst (1950) and in the late 1950's in the Wallowa Basin by Thompson and Haas (1960).

Coho eggs and adults were also transferred to the Wallowa River from Oxbow Hatchery (near Bonneville Dam) during 1964-68. Adult coho were trucked in only in 1964 when 300 adults were released in the Wallowa River at each of three sites: near Minam, near Lostine, and below Enterprise. During 1964-69, the Oregon Game Commission planted coho eggs from Oxbow Hatchery at a spawning channel constructed on Spring Creek, near Enterprise (Anderson 1969). Fry emerged and left the channel in mid March, and were counted in a trap at the outlet (Table 14). In 1969 only, a 4 acre pond was created below the spawning channel by placing stop logs in the creek. Coho emerging from the channel moved downstream into the pond where they grew rapidly and reached a mean size of 79 mm and 6 g by June 1 (Anderson 1969). Coho were allowed to leave the pond volitionally, so there is no record of how many remained there until the following spring.

Table 13. Releases of Coho into the Wallowa River, 1901-1950.

Year	Eggs Taken	Planted in Grande Ronde Basin No.	Size	Date	Origin	Hatchery	Area of Release	Reference
1901	7,532,300	7,532,300	eggs		Grande Ronde R.	Grande Ronde	Grande Ronde	Van Dusen 1903
1903	1,773,000				Wenaha R.			Van Dusen 1905
1906	527,000							Van Dusen 1905
1907	287,300	100,135	fry	04-30-07	Wallowa R.	Wallowa	Wallowa River	McAllister 1909
1907		100,000	fry	04-23-07	Wallowa R.	Wallowa	Wallowa River	McAllister 1909
1907		100,000	fry	04-25-07	Wallowa R.	Wallowa	Wallowa River	McAllister 1909
1907		100,000	fry	04-28-07	Wallowa R.	Wallowa	Wallowa River	McAllister 1909
1907		100,000	fry	04-18-07	Wallowa R.	Wallowa	Wallowa River	McAllister 1909
1912	4,227,000	0						Clanton 1913
1924		1,019,900	fry		Import	Wallowa	Wallowa River	B.R.F.C. 1925
1925	84,200	1,307,000	fingerlings		Import	Wallowa	Wallowa River	B.R.F.C. 1927
1929	40,000	160,000	fry		?		Wallowa Co.	B.R.G.C. 1931
1930		33,200	4", 12 mos.		?	Wallowa	Wallowa River	B.R.F.C. 1931
1931	213,160							B.R.F.C. 1931
1932		200,000	fingerlings		?	Wallowa	Wallowa River	B.R.F.C. 1933
1934		931,000	fingerlings		Import	Wallowa	Wallowa River	B.R.F.C. 1935
1935	510,470	500,000	fingerlings		Import	Wallowa	Wallowa River	B.R.F.C. 1937
1937	52,000	561,100	fingerlings		?	Wallowa	Wallowa River	B.R.F.C. 1939

B.R.F.C. = Bienuial Review of the Fish Commission of Oregon

Table 14. A summary of the operational success of the Spring Creek incubation channel over a five year period (Anderson 1969).

Year	Number of eggs planted Coho	Steelhead	Total Fry Live	Dead	% Hatch
1965	349,600		7,065	38	2
1966	200,000		31,081	80	15.5
1966		108,936	60,983	3,785	55.9
1967	307,664		228,397	2,172	74.2
1967		300,000	125,718	1,346	42
1968	300,000		175,724	1,183	58.6
1969	300,000		318,724	796	100

We compared the number of fry produced in the spawning channel to the number of coho smolts captured in rotary-screen trap boxes the following year (Figure 37). For this comparison, we estimated the number of fry produced from the 900 adults introduced in 1964 based on the following assumptions: (1) half of the fish were females, (2) each female spawned 2,500 eggs (average fecundity at Oxbow Hatchery [Howell et al. 1985]), and (3) 30% of the eggs survived to fry the next spring. These assumptions produce an estimate of 337,500 fry. Figure 36 shows abundance of fry leaving the channel matches well with the appearance of coho smolts in the trap boxes during 1965-70. Fry that reared in the 4 acre pond in 1969 contributed to the record spawner count of 114 fish in the Wallowa River in 1971 (see Table 11). Coho smolts captured in trap boxes during 1972-77 would have been the natural offspring of coho returning for one and two generations after the initial stocking.

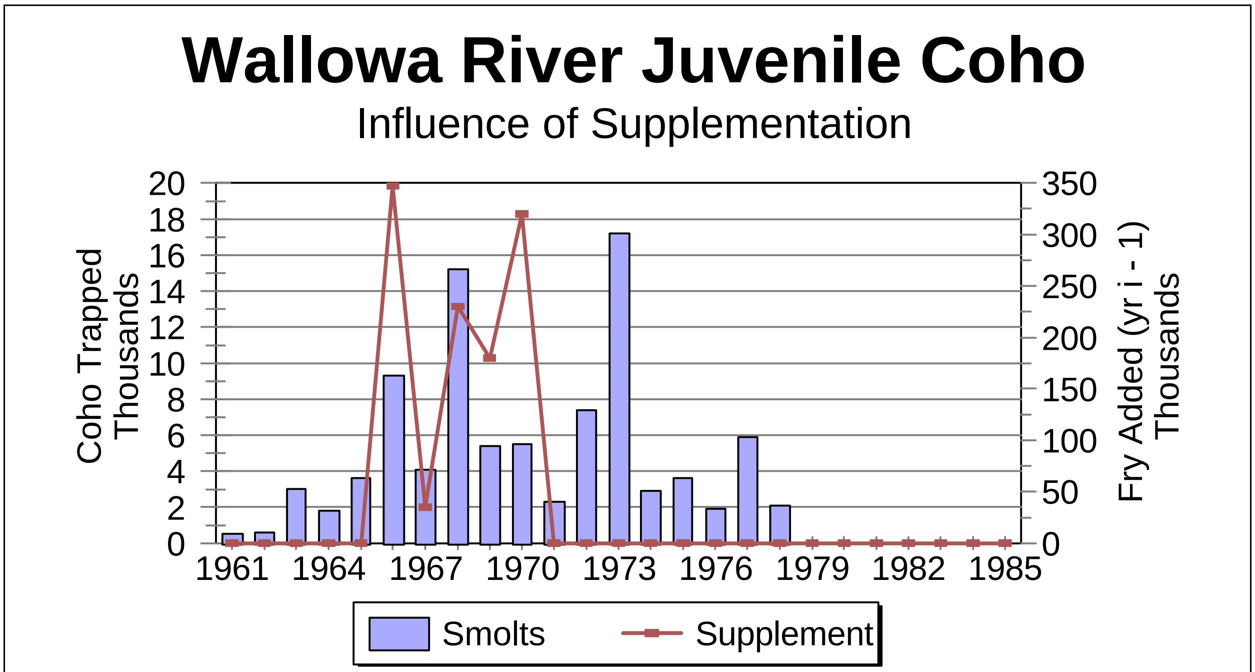


Figure 37. Comparison of juvenile coho catches in trap boxes at screened irrigation diversions with coho fry produced in the Spring Creek Incubation Channel (ODFW Data).

POPULATION CHARACTERISTICS

Because of the strong hatchery influence on coho produced in the Wallowa River during 1965-77, characteristics of the indigenous stock must be determined from data collected at the Grande Ronde and Wallowa River hatcheries during 1901-07. From these records, we can determine time of river entry, spawning time and fecundity. Coho began arriving at the Grande Ronde racks in mid September 1901. Spawning time in 1901 showed two peaks, one on the week ending November 4 and the second on the week ending December 2 (Figure 38). In 1906 and 1907 when fish were trapped in the Wallowa River, there were relatively few fish remaining to be spawned in late November (Appendix 10). The latter peak was also absent among fish trapped in the Wenaha in 1903 (Appendix 10). The later spawning fish may have been destined for the upper Grande Ronde system or may have spawned in Spring Creek or the Wallowa River immediately below the lake where winter water temperatures are likely to be higher than in other areas. Fecundity ranged from 2,700 to 3,000 eggs/female at the Grande Ronde and Wallowa River stations and averaged 3,671 eggs/female at the Wenaha River station. This latter fecundity is unusually high and may be in error.

Timing of coho migration can also be seen from counts of coho over McNary and Ice Harbor Dams. At McNary Dam, migration peaked in early September during 1954-65, with about 13% of the run passing in October. During 1983-89, the run was dominated by hatchery fish and the run still peaked in September, but the percentage of fish passing in October had doubled (Figure 39). Average time of passage at Ice Harbor Dam during 1962-68, was almost identical to that over McNary Dam (Figure 40).

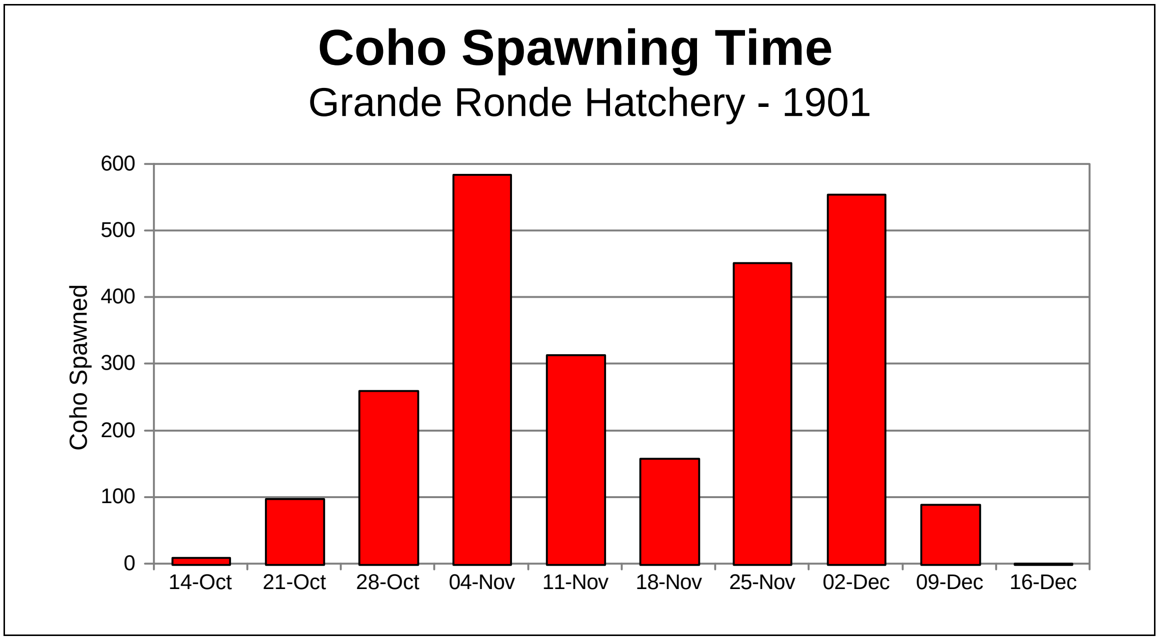


Figure 38. Number of coho spawned weekly at Grande Ronde Hatchery near Troy in 1901 (Van Dusen 1903).

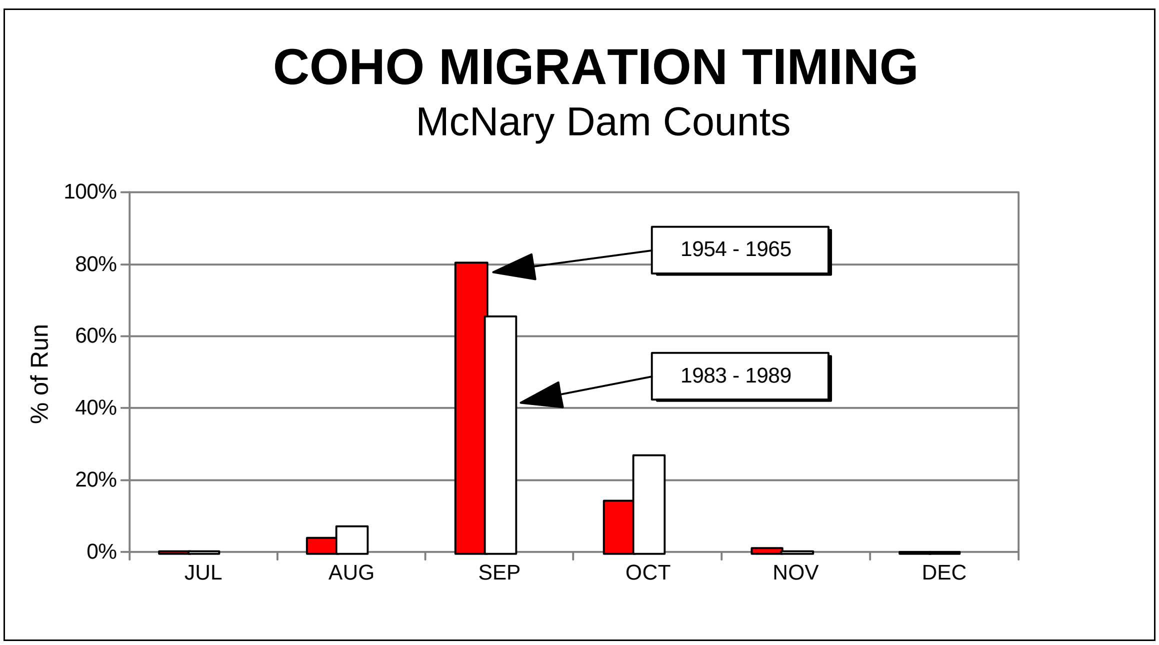


Figure 39. Proportion of the coho run passing over McNary Dam each month, 1954-1965 compared to 1983-1989 (USACE 1990).

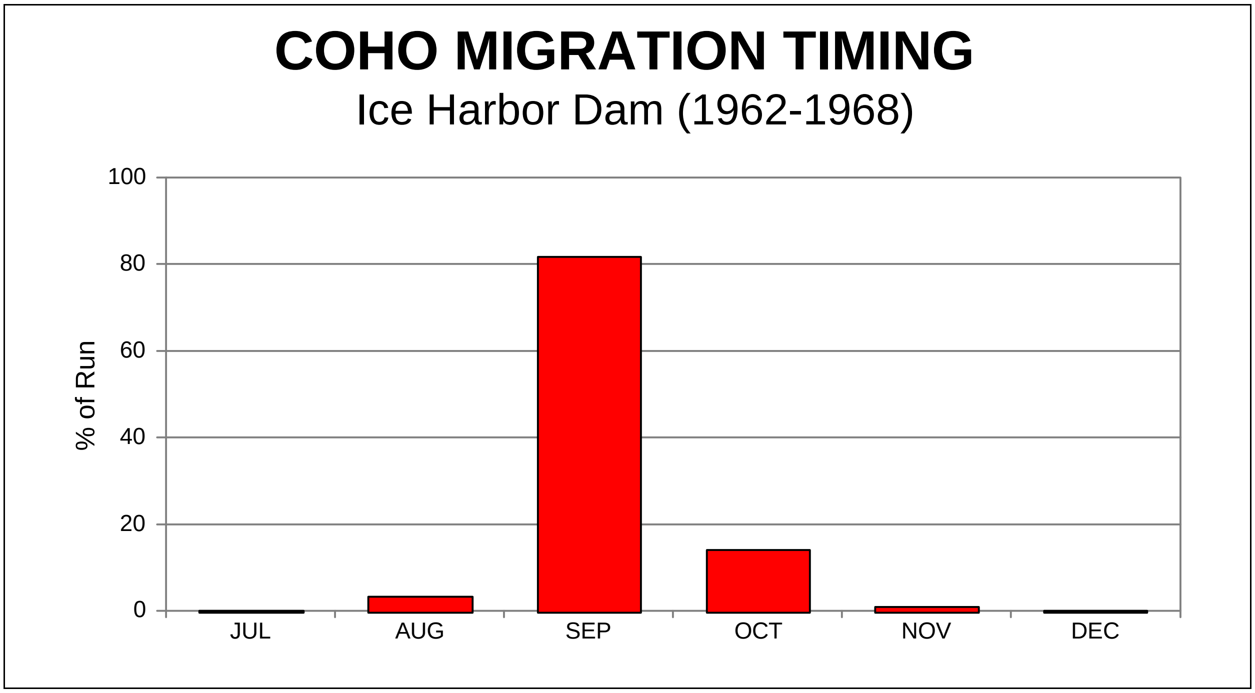


Figure 40. Proportion of the coho run passing over Ice Harbor Dam each month, 1962-1968.

Characteristics of the juvenile coho outmigration were studied in detail during 1965-67; however, these fish were predominantly Oxbow Hatchery stock. Coho smolts were captured and branded at traps throughout the Wallowa Basin and were recovered at Ice Harbor and McNary Dams. The estimated number of smolts leaving the Wallowa River at a point about 2 miles below Wallowa was estimated to be 34,700 in 1965, 92,500 in 1966, and 42,500 in 1967 (Anderson 1967). Mean lengths were 11.7 cm and 11.6 cm in 1965 and 1966. A scoop trap in the Wenaha River during March-May 1967 caught no coho. Coho branded in the Wallowa River and recovered at Ice Harbor were the latest migrants (mean June 13, 1966 and June 6, 1967) of all salmonids passing McNary and Ice Harbor Dams (Table 15; Park and Bentley 1968). In contrast, coho passage at Priest Rapids Dam peaked in mid April and mid May. The late migration of coho from the

Wallowa River reflects their genetic adaptation for the lower Columbia River where they had a short migration to sea. Average migration rate of coho from the Wallowa River to Ice Harbor Dam (263 mi) was 30 mi/d and to Bonneville Dam (433 mi) was 48 mi/d (data from ODFW, Enterprise). If efforts to reestablish coho proceed, a stock should be selected that begins its outmigration in late April to early May, so that smolts reach the estuary in mid May to early June.

Table 15. Timing of juvenile salmon passing Ice Harbor Dam, 1967 (from Park and Bentley 1968).

		Timing	
River of origin	**Species**	**Median**	**Range (all fish)**
Salmon River System			
Upper Salmon River	Chinook	April 26	4/26-5/18
Lemhi River	Chinook	April 21	4/11-5/18
South Fork Salmon River	Chinook	April 25	4/25-5/5
Pahsimeroi River	Chinook	May 5	5/4-5/9
Marsh Creek	Chinook	---[1]	---
East Fork Salmon River	Chinook	May 19	5/17-5/25
Grande Ronde River System			
Lookingglass Creek	Chinook	May 3	4/17-5/19
Minam River	Chinook	May 15	4/13-6/6
Upper Grande Ronde River	Chinook	May 11	4/17-5/24
Wenaha River	Chinook	May 8	4/18-6/5
Lower Grande Ronde River (Troy)	Chinook	May 1	4/20-5/26
Imnaha River	Chinook	April 26	4/18/5/24
Wallowa River	Coho	June 6	5/22-6/21

Sampling at Ice Harbor Dam began on March 25 and concluded on July 12

1. **No marked fish recaptured**

CONDITION OF COHO HABITAT

Physical Habitat

The freshwater habitats for all aspects of a coho's life in freshwater have changed since the time coho were abundant in the Grande Ronde Basin. Here, we review habitat as it affects each life stage, beginning with spawning.

Spawning Habitat

Some of the most important spawning areas for coho have been degraded by flow diversions, channelization, gravel compaction from nutrient loading and pollution from feed lots and irrigation return. The most popular spawning area during 1965-77 was in the Wallowa River from Dorrance Lane to the Wallowa Hatchery intake near Enterprise. Much of the land adjoining this section of the river is used for cattle feed lots during the late fall and winter, beginning about the time coho spawn. Cattle waste lines the river banks at these feed lots and is washed into the stream, causing pollution, siltation and gravel compaction. Coho probably spawned above Dorrance Lane bridge in the many river braided channels fed by warmer water from Wallowa Lake and springs. However, the braided channels are now one channel and many of the springs are presently used for domestic and livestock water.

Low flows at the time of coho spawning are determined mostly by the rate of water storage in Wallowa Lake. The pattern of flows, as measured by the USGS at Joseph indicate a dramatic reduction in flow during October through April, when water was stored in the lake (Figure 41). Recorded flow at Joseph during 1904-1914 provides a picture of flows when coho populations were self-sustaining. Comparison of flows in 1904-1914 with those in 1965-77 when coho were last present shows that flows during October and November, the time of spawning, were reduced by about 50% to about 30 cfs. This low flow, when braided into several channels, probably substantially reduces the usable spawning gravels from Dorrance Lane to Enterprise. During abnormally high run off, such as occurred in the early 1980's, flows do reach the natural mean of about 80 cfs, because the lake is full and natural flows are released. The extreme low flows in winter also make the streambed more vulnerable to freezing in the harsh winters, which would kill coho eggs.

The availability of spawning gravels in some of the basin's streams was estimated by Thompson and Haas (1960). They estimated that existing spawning gravels would support 200 redds in Hurricane Creek, 300 redds in Big Canyon Creek, 300 redds in Bear Creek, and 500 redds in Prairie Creek. However, most of Prairie Creek is presently unusable because of gravel compaction and silting that has resulted from organic sediment in irrigation return water. Thompson and Haas also recommended that coho be transplanted into Spring, Indian, and Clark creeks in the upper Grande Ronde Basin. Spawning areas in the Minam and Wenaha rivers are in pristine condition. Spawning gravel in the lower Lostine River has been dramatically reduced by channelization. Parkhurst (1950) reported there was much destruction of spawning habitat in the upper Grande Ronde Basin due to mining and irrigation diversions.

Habitat for Rearing and Downstream Migration.

This evaluation will be completed during development of the Hatchery Master Plan. A recent survey of several streams in the upper Grande Ronde Basin by the U.S. Forest Service indicates there has been a tremendous loss of rearing habitat in the last 50 years. For example, detailed surveys of Catherine Creek in 1940 compared with those completed in 1990 show at least a 76% reduction in pool surface area (personal communication with Jim Seddel, U.S. Forest Service, Corvallis). Pools are the preferred rearing habitat of coho (Reeves et al. 1989). Unfortunately, none of the Grande Ronde Basin below La Grande was included in this survey.

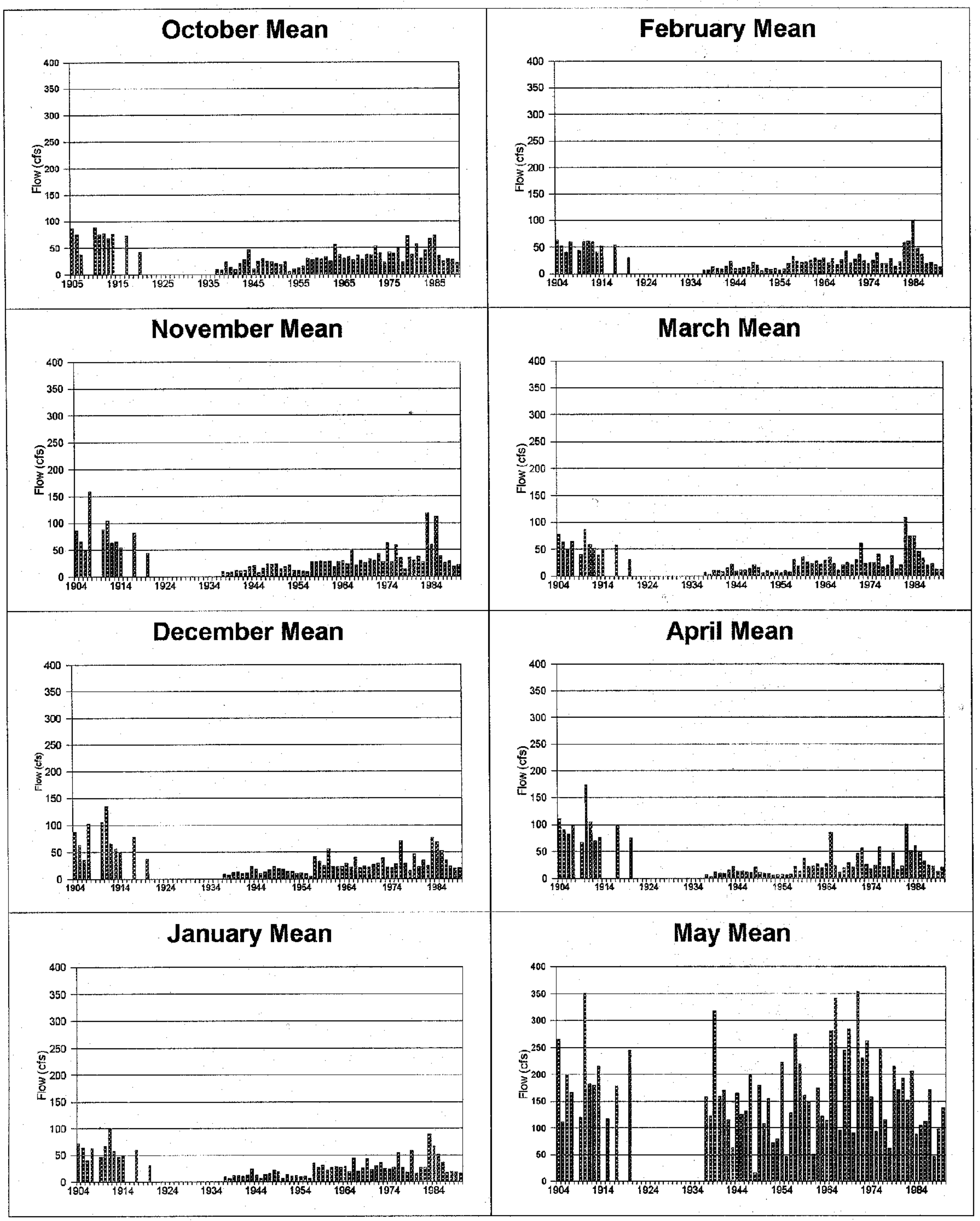


Figure 41. Mean monthly flows each year, 1904-1989, of the Wallowa River measured at the USGS gauge near Joseph.

Flows and river temperatures for downstream migration of coho in May within the Grande Ronde Basin are excellent (see Figures 2,3,5, and 41). Fish screens are in place on all diversions in areas of the basin accessible to coho, except in the Wallowa River for a distance of about 1.5 miles below Wallowa Lake.

Once coho smolts reach the Snake River, they must pass 8 dams to reach the ocean. Some of these smolts will enter collection facilities at Lower Granite, Little Goose and McNary Dams and be transported to below Bonneville Dam, while others will miss the collection facilities and swim the entire route.

Ocean Environment

There have been several studies in recent years indicating that the carrying capacity of the ocean in the Oregon Production Index (OPI) area (the Pacific Ocean south of Ledbetter Point, WA) may have been reached, such that survival of coho off of Oregon is now density dependent. This has been a controversial issue, with evidence presented both for and against density dependence for coho in the OPI. The latest analyses indicate that survival at sea is density dependent, although upwelling and ocean temperature are the dominant influences (Emlen et al. 1990). Survival of coho released from public hatcheries correlated negatively with the total of releases by public and private hatcheries. Releases of hatchery coho smolts steadily increased from 1960 through 1981, and have remained relatively stable since 1982 (PMFC 1990). Thus, ocean survival of coho from the Grande Ronde Basin may be reduced by competition with other coho. This reduction can be estimated with analyses presented by Emlen et al. (1990).

Environment for Upstream Migration

Losses of coho returning to the Wallowa River will also occur as they pass over the eight dams. These mortality rates will be estimated as a part of the continuing work. Once in the Grande Ronde River, coho encounter river temperatures in excess of 70°F (see Figure 5 and 21) and are likely to suffer substantial mortality. Mean water temperatures decline through the month of September and generally remain below 70°F after mid September.

Biological Habitat

Work under this topic will be completed in the Northeast Oregon Hatchery Master Plan.

POTENTIAL DONOR STOCKS

Several stock characteristics need to be considered in evaluating donor stocks for reintroduction of coho salmon into the Grande Ronde River Basin. Genetics, life history traits and availability of wild, natural and hatchery coho salmon need to be considered for compatibility with reintroduction objectives. We examined life history traits, including Columbia River entry timing, adult migration timing through the Columbia, Snake and Grande Ronde rivers, spawn timing, age and size at spawning, fecundity, fresh water rearing and distribution patterns, smolt size and out migration timing, and ocean migration patterns. Our objective was to match as many life history traits as possible to habitat conditions in the Grande Ronde River and to life history traits of coho populations that last inhabited the Grande Ronde Basin. We examined only stocks that we believe may be available for use as donors.

Adult coho from the last stock surviving in the Grande Ronde Basin (1966-1976) entered the Columbia River in late-August into early-September, they migrated through the Columbia and Snake rivers in September, entered the Grande Ronde River in October and spawned in November. This timing is similar to that was reported for coho in the Grande Ronde during the early 1900's. The average number of eggs per female was 2,700 to

3,000 (Van Dusen 1903, 1905, 1907). Fry likely emerged from the gravel late-March through April. Unlike chinook parr which exhibit a presmolt trend to move downstream, coho parr reared within a few miles of the spawning area. Smolts from introduced stock migrated downstream past Ice Harbor and McNary dams in mid-May to mid-June (Park and Bentley 1968), but because of their late arrival in the lower Columbia compared to other coho, we believe indigenous coho probably migrated out of the Snake River during late-April through May. The mean length of smolts was 11.7 cm in 1965.

Several stock characteristics necessary for sustained survival of coho in the Grande Ronde Basin are:

- Demonstrated high fitness for natural production
- Adult migration through the lower Columbia in late August/early September
- Energy reserves for migration up to 560 miles
- Spawning from mid October through November
- Resistance to diseases common in the Columbia River.

MIGRATION TIMING AND DISTANCE

In general, earlier river entry coho salmon spawn farther upstream within a basin than later migrating fish (Sandercock 1991). Coho salmon must migrate over 493 miles to reach the mouth of the Grande Ronde River. Many of the historic spawning beds are 50 or more miles above the mouth of the Grande Ronde. A coho donor stock must demonstrate the ability to adapt to early river entry and long distance adult migration. A donor stock should enter the Columbia River in late-August and to mid September.

Spawn Timing

Lister et al. (1981) found that spawn timing, and an inherited trait, is strongly correlated to tributary water temperature: coho salmon spawning in warmer tributaries spawn later than those spawning in colder tributaries. This correlation is a reflection of long-term selective forces that probably operate on the optimum timing for fry emergence. Most of the tributaries of the Grande Ronde have cold water temperatures during fall months, but an exception is the Wallowa River below Wallowa Lake. Water temperatures in this reach are affected by warmer water from Wallowa Lake and from natural springs. Spawn timing should be no later than early November in cold water streams and probably no later than late November in the Wallowa River. Van Dusen (1905) reported that some coho historically spawned in December, but there is likely a very limited location where a flow of warm water would have supported such a spawning time.

Smolt Migration

Weitkamp et al. (1995) notes that regardless of area of origin, ocean entry of coho smolts generally peaks in May. Park and Bentley (1968) determined that Grande Ronde natural coho stocks, which were greatly influence by hatchery programs, migrated late; late-May through the third week of June. We believe this smolt out migration period is too late in the Columbia River and this factor may have contributed to the extinction of the Grande Ronde coho population. Generally, conditions are best for smolt migration in the Columbia/Snake river migration corridor in May. However, many factors - natural flows, managed flows, nitrogen levels, spill, guidance and collection efficiency at collector dams, number of turbines in operation, changing agency policies, etc. - affect conditions during the smolt migration period.

Wild/Natural Parents

Availability of wild Columbia River coho stock is almost nil, because wild runs have been mixed with hatchery origin stocks. Almost the entire population of coho salmon now returning annually to the Columbia River system are hatchery fish (Johnson, et. al.,1991).

The number of naturally spawning coho salmon is limited, and likely there are two components of naturally spawning coho salmon; hatchery origin fish spawning naturally, and naturally produced fish with mixed degrees of hatchery ancestry (Johnson et. al. 1991). Therefore, donor stock for the Grande Ronde River is limited to stocks that have at least some hatchery ancestry.

Disease

Disease resistance is listed as one trait to consider when determining ecological/genetic importance of salmon populations (Waples 1991). Lower Columbia River coho salmon may exhibit an inherited resistance to parasites or diseases (Suzumoto et al. 1977, Pratschner 1978). However, coho salmon reintroduction into the Grande Ronde River must consider the following diseases: *Certomyxa shasta,* Erythrocytic Inclusion Body Syndrome (EIBS), *Cytophaga psychrophila* (CWD)*, Renibacterium salmoninarum* (BKD), and *Mysobolus cerebralis* (whirling disease). Whirling disease is of special concern, because it is not common or not found in many Columbia River sub basins. Whirling disease is common in the Wallowa River subbasin. Infected fish may stray into sub basins where the infectious agent is absent. Fish are more susceptible to whirling disease at a small size. Larger fingerling are not nearly as susceptible to whirling disease. Any reintroduction of coho into the Grande Ronde Basin should considered size-at-release as a tool to prevent spread of whirling disease.

Genetics

We have limited the donor stock assessment to Columbia River stocks because of genetic concerns. Genetic data indicate that Columbia River coho salmon are distinct from coastal Oregon populations, but similar to population from several coastal streams in southwest Washington. A dendogram of genetic relationships between coho populations from the West Coast, based on allozyme data, shows seven major clusters that are largely distinct geographically (Figure 42). Cluster VII includes all of the genetic samples from the Lower Columbia River, as well as those from southwest Washington coast. Two sub-clusters comprise most of the lower Columbia River samples; one consisting primarily of samples from Oregon. One sub-cluster contains a group of samples from the Clackamas and Clatskanie Rivers (Weitkamp et al., 1995).

Because there are two distinct temporal segments to the coho run entering the Clackamas River, additional genetic sampling has been initiated for coho in this stream to determine if the early and late portions of the run have different ancestry. Before such genetics sampling was begun, Cramer and Cramer (1994) concluded that the late run was the true indigenous stock, while the early run developed from introductions of hatchery stock. Their conclusions were based on the timing of coho counts over North Fork Dam on the Clackamas River, and on the record of hatchery liberations of coho into the basin. The recent genetics samples, using analysis of mitochondrial DNA from adult coho in the Clackamas early run, the Clackamas late run, the Sandy Hatchery, and Eagle Creek Hatchery tend to corroborate the conclusion of Cramer and Cramer (1994). Those tests showed that Clackamas early run differed only slightly from the Sandy and Eagle Creek runs, but those three differed substantially from the Clackamas late run (Ward 1996). Further, the Clackamas early run was genetically the most diverse of the four stocks (Ward 1996).

We find that the genetic distance between stocks is an important trait, because it appears to be negatively related to fitness for survival. Reisenbichler (1988) showed that the return (catch plus escapement) per smolt released of hatchery-reared coho was negatively related to the distance smolts were released from the natal stream (Figure 43).

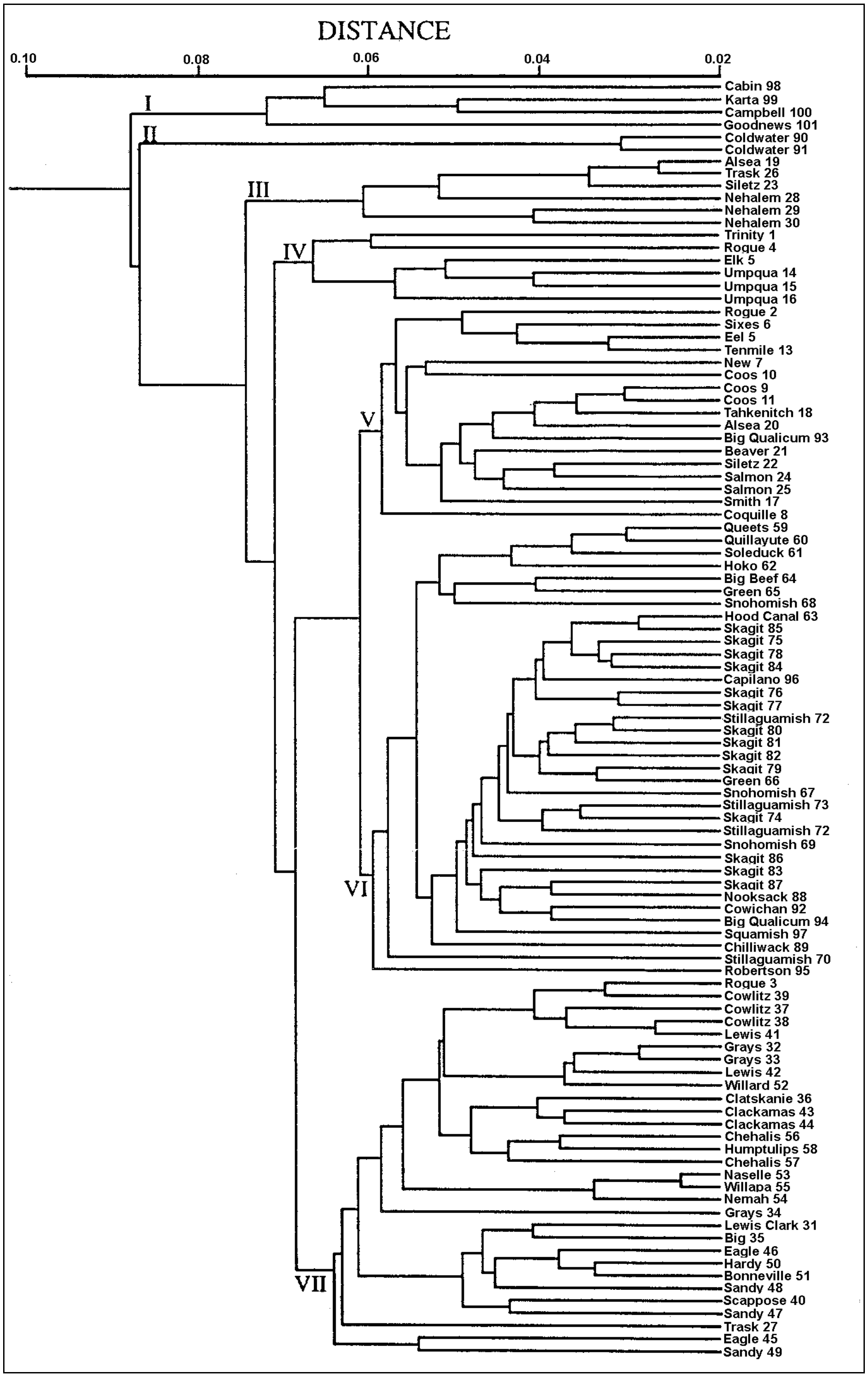


Figure 42. Dendrogram based on pairwise genetic distance values (Cavalli-Sforza and Edwards 1967) between 101 samples of coho salmon from the Pacific Northwest (Weitkamp et al. 1995).

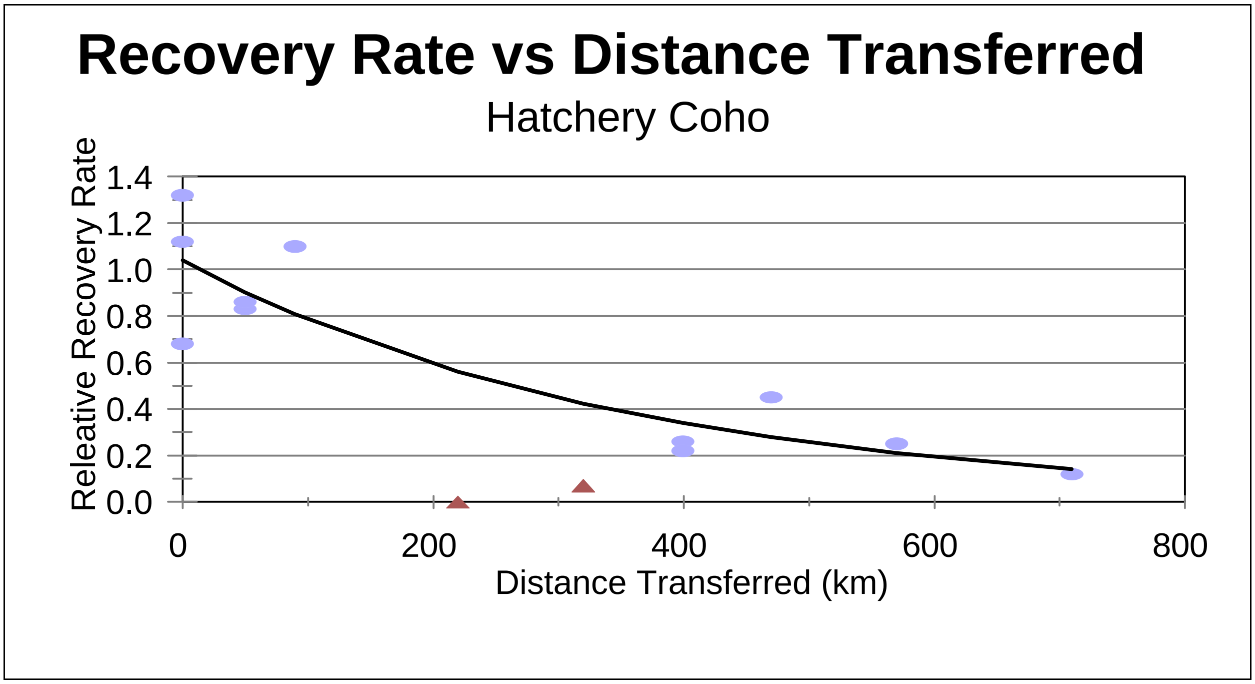


Figure 43. Relative (to local fish) recovery rate for transferred hatchery coho salmon versus distance transferred. Rates are based on recoveries in the fisheries and at the hatchery. Releases from Big Creek Hatchery, Oregon (triangles), were not used in fitting the curve.

Stock Selection Process

We examined life history trait information for five lower Columbia River coho salmon stocks to compare their life history traits with life history traits of Grande Ronde River wild/natural coho stocks that are now extinct. Stocks examined were the Cowlitz, Kalama (early), Clackamas (early), Sandy and Washougal. These stocks were chosen because they are available, they most closely emulate life history traits of natural Grande Ronde coho stocks, and their populations have remained fairly stable under current depressed population levels. Each of the stocks considered show timing of key life history events that overlaps with the timing for the indigenous Grande Ronde stock, including time of river entry, time of spawning and time of smolt outmigration (Table 16).

Table 16. Life history information for the indigenous population of Grande Ronde coho, and for lower Columbia Basin stocks considered as potential donors for reintroduction of coho into the Grande Ronde basin. The "score" reflects compatibility with the original Grande Ronde stock. Information, except for the Grand Ronde stock, is from Cramer et al. (1991).

River	Peak River Entry	Peak Spawn Timing	Peak Smolt Outmigration	Breeding Type	Score
Grande Ronde	early Sept	Nov.	mid May	Natural	
Cowlitz	late Oct. - Nov	late Oct. - Nov	May	Hatchery	Poor
Kalama-early	Sept.-early Oct	late Oct - Nov	May	Hatchery	Fair
Clackamas-early	Sept	Oct. Nov.	early Mid May	Natural	Good
Sandy	Sept.-early Oct	mid Nov.	May	Hatchery	Fair
Washougal	Sept.- early Oct	Oct. - late Dec	May	Hatchery	Fair

Analysis of the life history traits of five lower Columbia River coho salmon stocks indicate that the early spawning Clackamas River coho stock are the best suited as a donor stock for the Grande Ronde River. Clackamas early-run coho have the earliest time of river entry and spawning of the lower Columbia stocks, and are closest in those traits to the indigenous Grande Ronde stock. Most importantly, the Clackamas early run is the only stock among those considered that is naturally self sustaining, while all others are maintained by hatcheries. Each of the stocks considered appears to have traits that could be genetically adapted through natural selection to the ideal for the Grande Ronde Basin, but the long time and high mortality associated with such selection would reduce the probability of success. On the other hand, the Clackamas early run coho have already undergone multiple generations of natural selection to become fit for natural reproduction in an environment like that of the Wallowa River.

Horner and Bjornn (1981) state that coho stocks from Bonneville Hatchery were originally derived from early run fish destined for upriver spawning areas. D. Barrett, manager of the Bonneville Hatchery reported to D. Bryson, NPT, (sometime during the late- 1980's) that very early run coho salmon still enter Tanner Creek adult collection facilities at Bonneville Hatchery. D. Barrett reports poor survival of very early run coho collected at the Tanner Creek trap because of the extended length of time between capture and spawning. D. Bryson speculates that the early run of coho captured in the Tanner Creek trap may have originated from Yakima River and/or Snake River coho salmon stock. Information is not available to determine genetic or life history traits of the very early Tanner Creek coho salmon stocks. However, D. Bryson (personal communication, May, 1997) recommends incorporation of very early run Tanner Creek coho salmon stock into the Grande Ronde Basin coho salmon donor stock.

Mullan (1984) analyzed attempts to reestablish runs of coho in the middle Columbia from the Yakima to the Okanagan rivers and concluded the failure was caused by use of lower Columbia hatchery stocks which were genetically unsuitable. Additionally, this stock, often called Toutle stock or early run, has produced poor returns from hatchery reared smolts released in the Yakima River during 1987-88 (personal communication with Tom Scribner Yakima Indian Nation). Based on these findings, we believe emphasis should be given to choosing a stock whose parents have adapted to their environments and now sustain natural populations. Because the Clackamas early run coho is the stock best suited as a donor, we describe them in more detail here.

Early Clackamas River Coho Stock

During the period 1962-1979, many thousands of non-native coho were introduced into the Clackamas River. Unlike the native Clackamas coho which returned to the Clackamas River in October and spawned in February and March, the introduced coho developed a pattern of entering the Clackamas in September and spawned in October and November. Few hatchery coho have been stocked above the counting station at North Fork Dam since 1980, and natural production has sustained the run since then. The early and late coho runs in the Clackamas River are the only self-sustaining natural runs of coho in the Columbia Basin. These naturalized early-run and native coho tend to spawn further upstream in the basin from RM 48.5 to RM 68, and juvenile rearing occurs in the upper watershed above the late spawning stock of coho. Water temperatures in the spawning area average about 41°F in November, drop to 37°F in January, and do not reach 40°F again until mid April (Cramer and Cramer 1994). Nearly all smolt migration occurs in April and May. Ocean distribution is mostly south of the Columbia River, based on CWT recoveries of coho from the hatcheries from which this run was derived.

Size of smolts produced by early run Clackamas coho stocks ranges from 110 to 175 mm with an average of about 115 mm (Cramer and Cramer 1994). Mean lengths of Wallowa River coho smolts were 117 mm and 116 mm in 1966 and 1967 (Anderson 1967).

Migrating early run coho salmon must past three dams on the Clackamas River; the North Fork Dam (RM 31.0), The Faraday Diversion Dam(RM 29.0), and the River Mill Dam (RM 23.5). The North Fork Dam has a hydraulic head of 134 feet, the River Mill Dam has a head of 85 feet, and the Faraday Diversion Dam has a head of 125 feet (Cramer and Cramer 1994). Grande Ronde River stock coho must pass eight dams each with heads of approximately 100 feet.

Fish are counted as they pass through the fish way over North Fork Dam (RM 31). Monthly coho counts of the "early" adult coho stock follow:

			Early Stock		
Year	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Total**
1980	0	110	9	6	125
1981	1	463	168	140	772
1982	46	891	464	38	1,439
1983	0	76	5	4	85
1984	0	123	116	46	285
1985	32	1,450	711	112	2,305
1986	0	867	289	256	1,412
1987	11	363	164	30	568

Early Stock					
Year	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Total**
1988	11	806	182	125	1,124
1989	6	475	278	113	872
1990	0	151	149	83	383
1991	0	1,220	374	261	1,855
1992	0	1,100	362	187	1,649
1993	0	77	38	4	119
1994	33	1,634	408	59	2,134
1995	13	680	405	414	1,512
1996	0	47	40	0	87

SIMULATION OF REINTRODUCTION

We used a simulation model to estimate the escapement and harvest that could be achieved from various reintroduction strategies. Because Clackamas early-run coho was identified by the authors as the stock of choice for a brood source, we used parameter values in the simulation model that would be appropriate for that stock. Additionally, we used the model to simulate a range of productivities (recruits/spawner) and harvest rates, because these parameters are not fixed, but typically vary over time. The model incorporates parameters for mortality of coho as they pass dams, both as smolts migrating downstream and as adults migrating upstream, because this mortality will be added to that which Clackamas coho experience while passing to and from the Clackamas River.

MODEL STRUCTURE

The simulation model was structured to follow key steps in the life history of coho salmon. The model begins with the number of adults that survive to spawn (Figure 44). The number of parr that these spawners produce in the next generation is predicted according to a Ricker stock-recruitment function. Parr suffer mortality over winter and then become smolts the next spring. Smolts are assigned a survival rate to the time that they become harvestable adults (age 3) in the ocean (ocean recruits). The survival rate from smolt to ocean recruit is intended to reflect survival without main-stem dams, so that passage mortality is added in as a separate step in the model. Coho are assumed to be harvested in the ocean only at age 3. A portion of the maturing fish entering the Columbia River each year are harvested in the river. All adults, hatchery or natural, are assumed to have equal fitness for natural reproduction.

The parameter values we used in this model are as follows:

Parr Carrying Capacity	292,000
Parr-to-smolt Survival	30%
Smolt-to-Adult survival rate (pre-dam)	5%
Smolt passage mortality per dam	10%
Ricker α (max. ocean adults/spawner)	6.7
Ricker ß (from parr capacity)	1.2×10^{-3}
% remaining fish that mature at age 3	100%
Ocean Harvest Rate	15-35%
River Harvest Rate	15-35%

Derivation of the parameter values and mathematical functions for each of these life cycle segments is described in the report sections that follow.

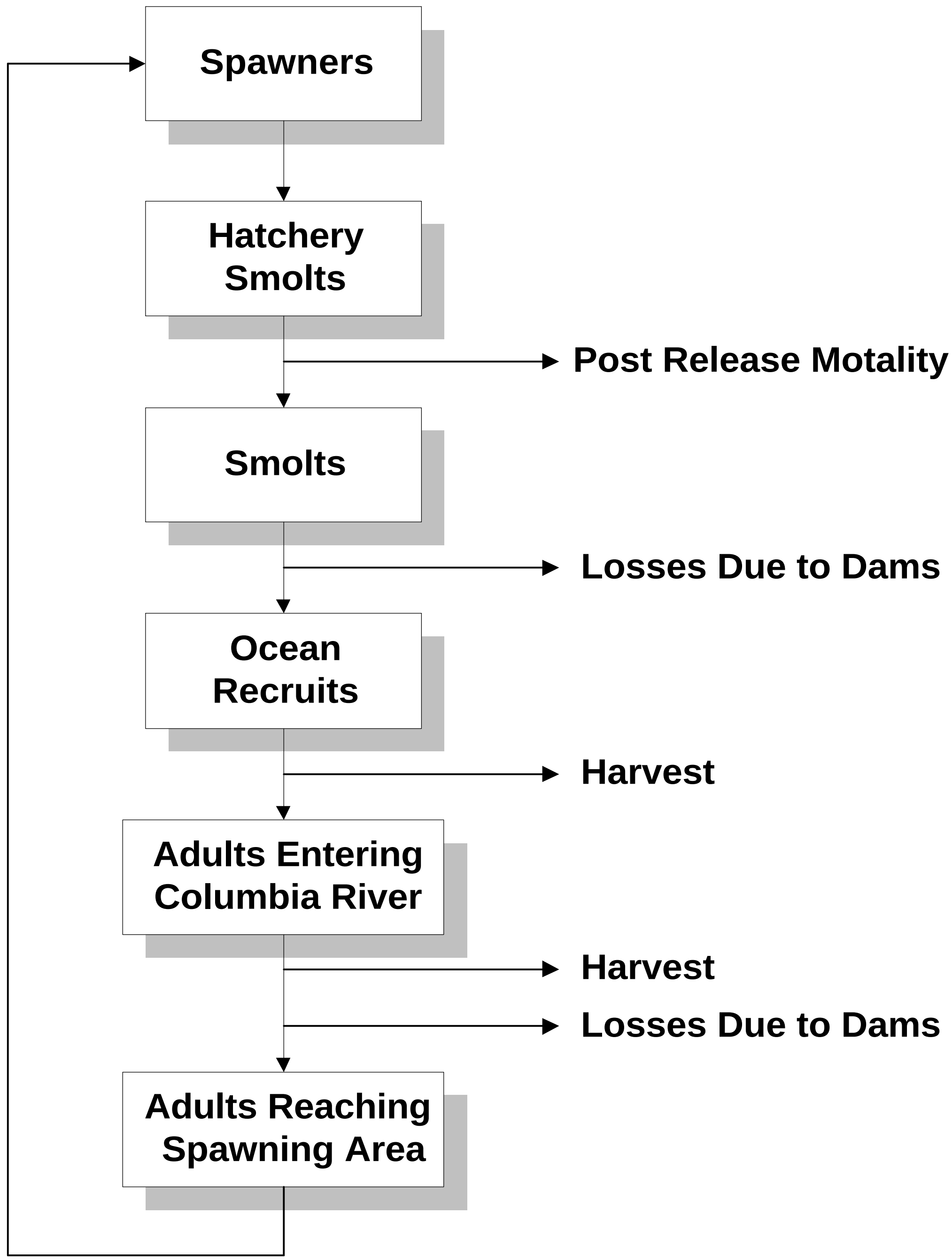


Figure 44. Flow diagram of our population model for coho salmon produced in the Grande Ronde River Basin.

PARAMETER VALUES

Spawner-to-Smolt Survival

We treated density-dependent survival in freshwater from spawning until smolting in three stages. First, we developed a Ricker function to reflect survival from spawner to parr. We refer to "parr" as juveniles in the fall of the first year of life. The next spring they become "smolts" as they start their seaward migration. Second, and as a part of the first stage, we estimated the habitat carrying capacity for fingerlings.

Spawner to Parr

Because spawner-recruit functions are not typically calculated from the spawner to the parr stage, we began by drawing on spawner-to-adult data, and then back-calculated the abundance at the parr stage. We assumed the relationship between parent spawners (P) and the number of their offspring recruited into the ocean fishery (R) was approximated by a Ricker stock-recruitment curve:

$$R = \alpha P e^{(-\beta P)}$$

where α = slope at the origin (maximum recruits per spawner)

β = 1/(Spawners needed for maximum recruitment)

Alternatively, the Ricker equation can be expressed as:

$$R = Pe^{a(1-P/Pr)} \qquad \textbf{(3)}$$

where,

$a = \ln(\alpha)$

P_r = Number of parents at the level of replacement (the level where R = P)

We introduce this additional form of the function, because it is useful for estimating the value of ß for each stream, based on the estimated smolt capacity of that stream. We can estimate smolt capacity, which in turn can be converted to the maximum achievable number of recruits, R_m, by applying the expected smolt-to-adult survival rate. We assume that smolt-to-adult survival rate is not influenced by density dependence.

The following is how the Ricker ß parameter can be estimated from parr capacity. Ricker (1975) demonstrated that the maximum number of recruits, R_m, is given by:

$$R_m = (e^{a-1})(P_r)/a \qquad \textbf{(4)}$$

If we can obtain an independent estimate of α from a comparable population, then we can substitute a = ln(α) into equation (4) and we can substitute the estimated parr carrying capacity (converted to adult recruits) for R_m in equation (4), so that we can solve for P_r. Once we have solved for Pr, it can be shown that,

$$ß = a/P_r$$

so we can solve for ß.

The values of α and ß reflect the units of measure applied to P and R. In the case we use, α is in units of parr per spawner and β is units of 1/spawners. If R is expressed in terms of parr, α will be substantially greater than if α is expressed in terms of adults in the ocean.

The α parameter represents the number of recruits (R) per parent spawner (P), and thus is a measure of stock productivity. No estimates of the α parameter are available for the indigenous Grande Ronde stock, so we assumed it was approximated by the α = 6.7 estimated for Oregon coastal coho (ODFW 1982). That value excluded jacks from the count of adults and the recruits were age 3 adults in the ocean before fishing began. Cramer and Cramer (1994) estimated that the value for a comparable α representing the late-run stock of Clackamas coho ranged from mean near 3.0 during the 1980's to a mean near 8 for the 1960's, so we also ran simulations with these values. Note that passage mortality is deducted after recruitment is calculated, so the use of a Ricker α value comparable to coastal coho is reasonable. After passage mortality is added in for each dam (the mortality estimate is actually the average for a river segment from one dam to the next and includes both the natural and dam-related mortality), the net stock productivity for an upriver stock (such as in the Wallowa River) is far less than that for a lower Columbia or coastal stock.

Estimation of Parr Capacity

We adapted the Smolt Density Model (SDM), developed by the Northwest Power Planning Council, to estimate that the total production capacity for coho parr in streams of Wallowa County was about 292,000 parr. The SDM considers stream section length, average width, proportion of area which is accessible, use type and habitat quality. Two subjective values were assigned: 1) “use type”, which was either spawning and rearing or rearing only, and 2) “habitat quality” which was either excellent, good, fair or poor. The values we used for each stream reach and its estimated parr capacity are presented in Appendix 11. The habitat quality ratings were assigned by Ken Witty, the fisheries biologist that managed these streams for ODFW for over 20 years. The estimates of stream length and width between each tributary confluence were taken from the EPA River Reach database (NPPC 1989). Stream widths over 60 ft were set at 60 ft to reflect the tendency of juveniles to rear within 30 ft of shore in large stream channels. The density of parr that could be produced was set in the model at 0.30, 0.228, 0.15, or 0.075 fish/m^2 for habitat rated as excellent, good, fair, and poor, respectively (NPPC 1989). These values are derived from counts during late summer in fully seeded habitat. In portions of the stream not likely to be used for spawning, but that would be used for rearing, these values were reduced to 0.80, 0.023, 0.015, and 0.008 fish/m^2 (NPPC 1989). Thus, stream surface area was multiplied by fish/m^2, according to habitat quality rating, to estimate parr capacity (Table 17). These estimates of parr capacity combined with the assumed Ricker productivity parameter of $\alpha = 6.7$ for spawner to adult recruit were used to calculate the Ricker parameters for the spawner to parr life stage (Table 18).

Table 17. Coho parr capacity in streams of Wallowa County, as estimated by the Smolt Density Model developed by the Northwest Power Planning Council (1989). Summarized from Appendix 11.

STREAM	MILES	PARR PRODUCTION POTENTIAL
Wallowa River	51.2	65,833
Wenaha River	41.8	41,565
Minam River	59.4	111,363
Deer Creek	12.5	4,409
Bear Creek	19.2	11,853
Lostine River	25.9	52,093
Spring Creek	8.5	2,355
Hurricane Creek	4.2	933
Parsnip Creek	0.6	74
Prairie Creek	10.4	1,774
TOTAL	**233.7**	**292,252**

Table 18. Parr capacity and statistics of the Ricker function calculated for converting spawners to parr, given that Ricker α = 6.7 for spawners to ages adult recruitment.

Stream	Parr Capacity	Spawners at Replacement	Parr Beta	Spawners for max Production
Wallowa	**65,833**	2,445	2.50E-03	401
Wenaha	**41,565**	1,543	3.95E-03	253
Minam	**111,363**	4,135	1.48E-03	678
Deer	**4,409**	164	3.73E-02	27
Bear	**11,853**	440	1.39E-02	72
Lostine	**52,093**	1,934	3.15E-03	317
Spring	**2,355**	87	6.98E-02	14
Hurricane	**933**	35	1.76E-01	6
Parsnip	**74**	3	2.22E+00	0
Prairie	**1,774**	66	9.26E-02	11
Total	**292,252**	**10,852**	**5.62E-04**	**1,779**

Critics of the SDM believe the model tends to over-estimate anadromous fish production potential. For this reason, we were conservative in assigning values to habitat quality. Production potential estimates presented above, if biased, are conservatively low. It is our opinion that improved habitat conditions, especially in the Wallowa River, would greatly increase coho smolt production potential in Wallowa County streams. Also, smolt production potential estimates do not include streams in the upper Grande Ronde.

Parr-to-Smolt Survival Rates.

We estimate that overwinter survival for parr to smolt the following spring averages 30%, based on data for spring chinook juveniles in the Snake River Basin. Petrosky (1990) used PIT tagged chinook to estimate overwinter survivals of 26% in the upper Salmon River and 31% in the Crooked River (tributary of the South Fork Clearwater). Fast et al. (1991) estimated overwinter survival for juvenile spring chinook in the Yakima River

Basin to range from 22% to 49%. Lindsay et al. (1986) estimated overwinter survival of spring chinook parr in the John Day River averaged 30% during 3 years of study. We did not find estimates of coho over-winter survival in high-elevation streams, so we used the similar-sized spring chinook as a surrogate.

Smolt-to-Adult Survival Rate

We assumed that smolt-to-adult survival rate, if no dams were in place, would average 5%. This was about the median survival from smolt to age 3 recruitment for 16 broods of coho from Cowlitz Salmon Hatchery (Cramer 1996b) on the lower Columbia where there are no dams to pass. Although 5% was about the median survival, survival ranged widely between broods from a low of 0.2% to a high of 10%. Further, survivals during the 1980's tended to be substantially less than those during the late 1960's, indicating a strong tendency for ocean survival to vary cyclically (Cramer 1996b).

Hatchery smolts, which will be reared in a semi-natural environment, were assumed to have an immediate loss of 35% after release (Maynard et al 1995), and we subtracted this loss before combining the hatchery and natural smolts. That is:

$$Smolts_{(H+W)} = Smolts_{(W)} + (Smolts_{(H)} \times 0.65)$$

Where	Smolts	= number of smolts
	H	= hatchery
	W	= wild or natural

Mortality of Smolts During Dam Passage

We assumed passage-related losses per dam averaged 10% under current conditions. The net survival past eight dams was 43%. Our assumption is based on data for spring chinook, because there is little data on coho survival during passage of Columbia River dams (most coho are produced below Bonneville Dam). Raymond (1988) used 15% loss per dam for yearling chinook to adjust his smolt-to-adult survival data between years in which there were different numbers of dams in the migratory pathway; however, recent studies have demonstrated that mortality of fish passing through the turbines and through the reservoirs is less than previously thought. Anderson et al. (1996) summarize the findings from recent studies with PIT tags and inflatable balloon tags to estimate mortality of juveniles through various passage routes. The mortality of yearling chinook through turbines averaged over six studies was 10% for standard operating conditions. Mortality over the spill or through the bypass systems was estimated at 2%, based on all available studies. Recent PIT tag studies of chinook smolt survival through the Snake River have indicated that total mortality is generally about 10% from the tailrace of one project to the tailrace of the next, and most of this mortality can be accounted for in dam passage itself (Muir et al. 1995).

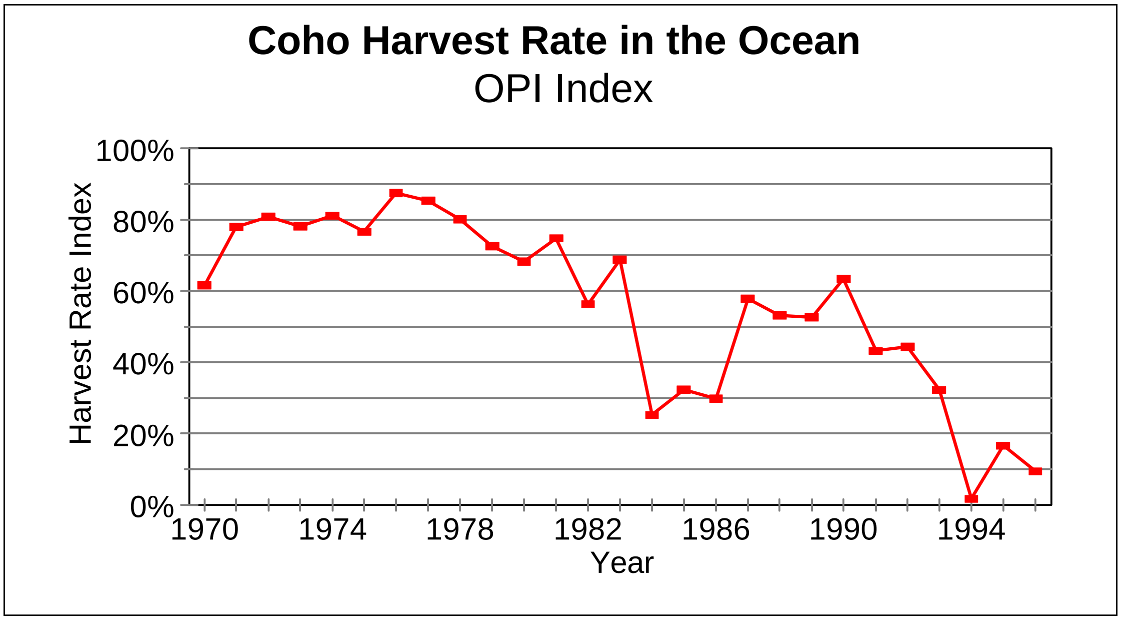
Harvest Rate

Harvest rates on coho in the ocean and in the lower Columbia River will have a major impact on the ability of the stock to sustain itself. Ocean harvest rate of coho in the OPI averaged 48% in the period 1982-1989 (Figure 45, PMFC 1990). The inriver harvest rate in zones 1-5 (downstream from Bonneville Dam), based on total catch and the estimated minimum inriver run, averaged 70% from 1984 to 1988 (Figure 45). The recent combined harvest rate for ocean and lower Columbia River would thus equal about 85%, without correction for hooking-related mortality in the ocean or mortality associated with net dropout in the Columbia. Additional harvest would occur above Bonneville Dam. These harvest rates have been the primary cause for the near elimination of wild coho populations below Bonneville Dam.

We used two different harvest scenarios in our simulations to represent combinations of harvest rates in the ocean and river that may occur in the future. The Oregon Coastal Salmon Restoration Initiative stipulates that ocean harvest rates for coho will remain at less than 15% until spawning escapement increases sharply, and that even after population recovery, harvest rates will be limited to 35% or less. Thus, future harvest rates on Columbia Basin coho are likely to fall within the lower range of harvest rates experienced in recent years. Recent harvest rates are substantially less than were experienced by coho during 1970-1990 (Figure 45). The large decrease in harvest rates in the 1990's, combined with the expectation that these lower rates will continue into the future, is a key reason that persistence of naturally producing coho in the Columbia Basin has much greater chances of success now than previously. The future of in-river harvesting above Bonneville Dam (Zone 6 fisheries) is unknown, but is also likely to be restricted to minimal levels because of endangered species concerns for other upriver runs of salmon and steelhead.

The harvest rate scenarios we simulated, and the recent history they represent were:

YEARS REPRESENTED	RIVER HARVEST RATE	OCEAN HARVEST RATE
1994-1996	35%	15%
Future	15%	15%



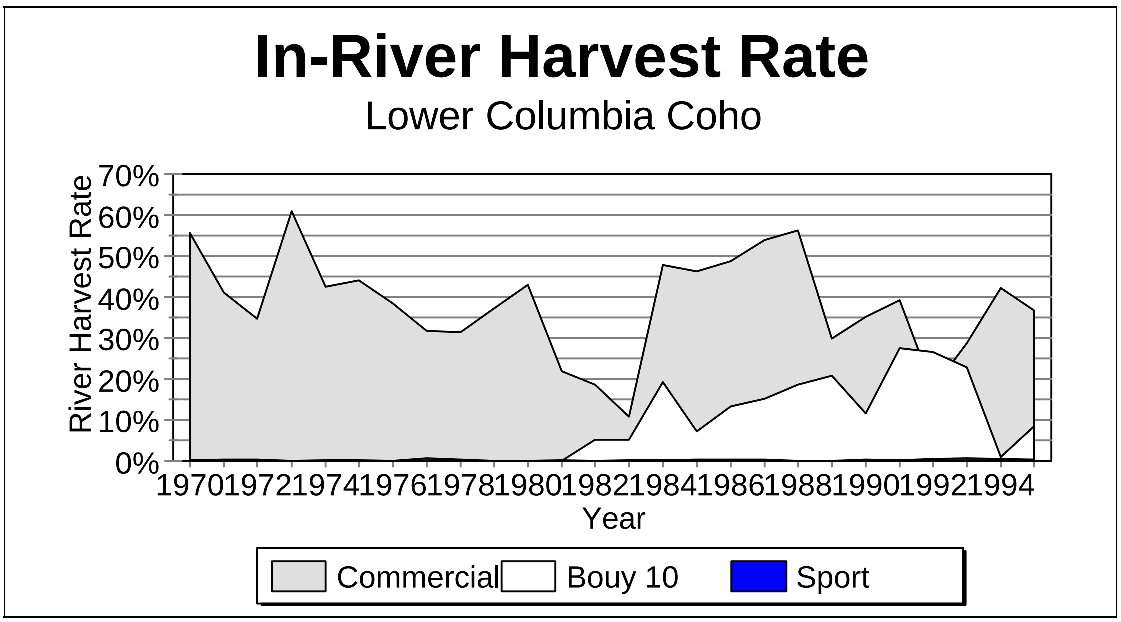


Figure 45. Proportion of adult coho that were estimated to have been harvested in the ocean (top graph) and in the Columbia River (bottom graph) during 1970-1995. Ocean harvest rates were estimated from the Oregon Production Index (OPI) (WDFW and ODFW 1996). River harvest rates were calculated for early-run coho based on landings and minimum run size reported by WDFW and ODFW (1996).

Mortality of Adults During Upstream Passage

We used a mortality rate of 5% per dam for adults migrating upstream. Chapman et al. (1991) reviewed estimates of interdam loss and concluded 95% survival per dam was the most reasonable estimate for spring chinook. NMFS (1992) estimated that survival of stream-type chinook past all eight dams into the Snake River Basin was 66%, which is equivalent to 95%/dam. We assumed survival of coho would be similar.

SIMULATION RESULTS

We completed our simulations in two stages. First, we simulated the catch and spawner escapements that would occur without supplementation under a variety of survival and harvest scenarios. Second, we simulated catch and spawner escapement for a variety of supplementation rates, given the most probable set of passage survival and harvest rates. We initiated all simulations with 1,000 adult recruits in the ocean, and ran the simulation 30 years into the future with survival and harvest rates held constant. We repeated these simulations for Ricker α values of 3, 6.7, and 8 to represent the poor, average and good conditions for ocean survival.

Results Without Supplementation

The simulations indicated that the population will not sustain itself by natural production alone at the expected levels of passage survival and harvest rate. The combination of passage mortality (a type of harvest) and recent harvest rates are equivalent to an 84% harvest rate ("average" scenario, Table 19). The calculated harvest rate that would produce maximum sustainable yield (MSY) at the expected stock productivity (α = 6.7) is about 70% (ODFW 1982). If losses from fish passage can be reduced, and harvest is reduced further from its present level, the population could become self sustaining. We simulated improvements in passage survival for which downstream mortality was only 5% per dam and upstream mortality was only 2.5% per dam. Under such a scenario (Btr Passage), with no change in harvest rates, the population could be self sustaining and would stabilize at a spawner escapement of just under 1,000 fish (Figure 46). We also simulated a reduction in river harvest rate down to 15%, with ocean harvest rate remaining at 15%. Under the reduced harvest scenario (Lwr Harvest), with average passage survival, the spawner escapement would stabilize at just under 500 fish (Figure 46). We also simulated a "best case" scenario for which the improved passage survival and the reduced harvest both occurred, and the spawner escapement stabilized at about 1,350 fish (Figure 46). This escapement is near that estimated to achieve full natural production. However, even this scenario leaves little hope for consistent harvest within the Grande Ronde basin, because spawner escapement under the best case scenario just approached the target escapement, <u>after harvest</u>, that would produce the greatest harvestable surplus over the long term. Cramer (in press) demonstrated that harvest rates for coho, where variation in survival between years is large, would produce the greatest yields over the long term if they were targeted to allow spawner escapement that produced maximum natural production.

Table 19 Values of passage mortality and harvest rate used in the four scenarios that were simulated naturally produced coho salmon in the streams of Wallowa County.

	Downstream Passage		Harvest			Upstream Passage		**Overall**
Scenario	Mortality per dam	**Total Mortality**	Ocean Rate	River Rate	**Total Rate**	Mortality per dam	**Total Mortality**	**Man-caused Mortality**
Average	10.0%	**57.0%**	15.0%	35.0%	**44.8%**	5.0%	**33.7%**	**84.2%**
Improved Passage	5.0%	**33.7%**	15.0%	35.0%	**44.8%**	2.5%	**18.3%**	**70.1%**
Reduced Harvest	10.0%	**57.0%**	15.0%	15.0%	**27.8%**	5.0%	**33.7%**	**79.4%**
Best Case	5.0%	**33.7%**	15.0%	15.0%	**27.8%**	2.5%	**18.3%**	**60.9%**

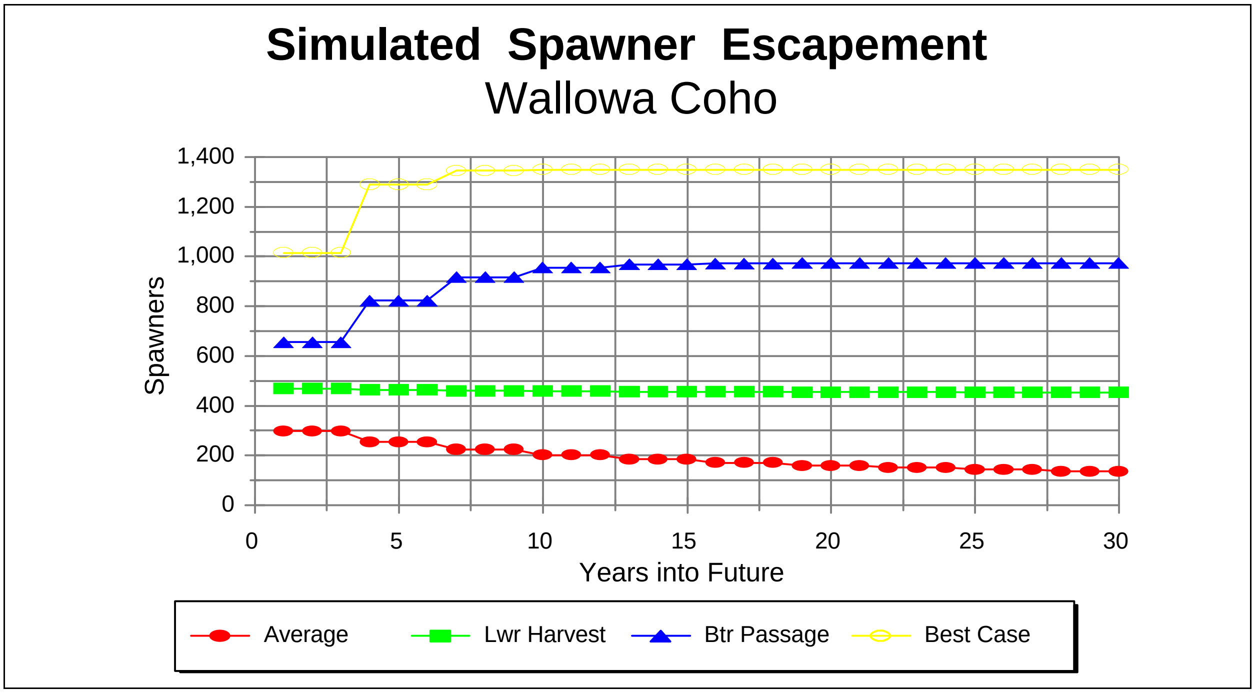


Figure 46. Simulated annual escapement of coho spawners into Wallowa County streams that would result under four scenarios of passage mortality and harvest rates. See Table for parameter values in each scenario.

We also completed simulations for low and high productivity levels (recruits per spawner). These simulations showed that if $\alpha = 3$, the level observed for late-run Clackamas coho in recent years, then a natural run initiated with 1,000 recruits would go extinct in less than 30 years, for the “average” and “reduced harvest” scenarios (Figure 47). Even under the “best case” scenario, the run would barely hang on with about 250 spawners. If α increased from the average of 6.7 up to $\alpha = 8$ (the value observed for late-run Clackamas coho during the 1960's), then spawner escapement under each scenario of fish passage and harvest would be about 200 fish higher after 30 years than with the expected $\alpha = 6.7$ (Figure 47).

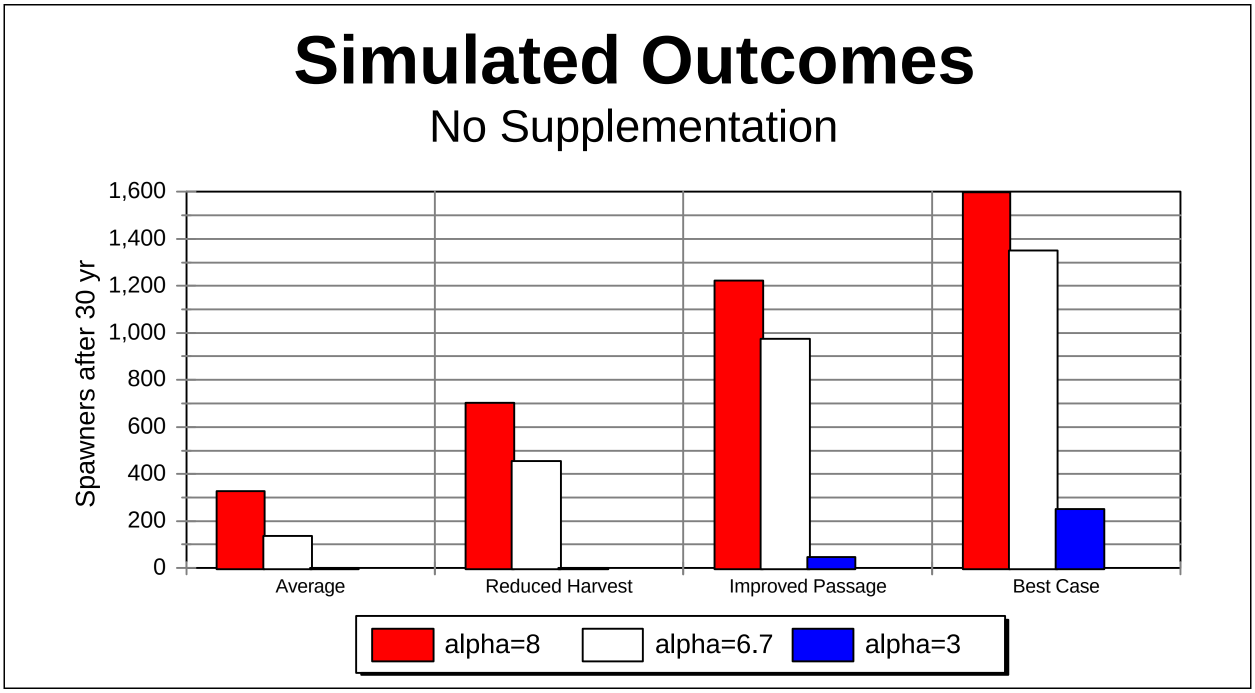


Figure 47. Simulated spawner escapement after 30 years of natural production of coho in Wallowa County, given three levels of stock productivity (Ricker α) and the “average” scenario for passage mortality and harvest rates.

This first stage of simulations indicates it is unlikely that natural production of coho can be self sustaining under present conditions. Although stock productivity is likely to increase to α = 8 or higher in years of high ocean survival, it is also likely to drop below α = 6.7 in years of low ocean survival. It may be possible to achieve the improved passage survivals that we used in the “improved passage” scenario, but this remains speculative, and should not be the basis for hatchery planning. Similarly, the “reduced harvest” scenario would be tenuous at best, because of the strong desire by the public to harvest salmon. Therefore, these simulations indicate that reestablishment of naturally reproducing coho in the streams of Wallow County is likely to require continuous supplementation from fish reared in a hatchery.

Results With Supplementation

We simulated a variety of supplementation rates for the “average scenario” of passage survival and harvest rates with the Ricker $\alpha = 6.7$. This is the scenario we believe to be the most probable that Wallowa coho will face over the long term. Without any supplementation, the natural spawner escapement would tend to be around 100 fish, and this escapement increased to near 1,600 fish if 200,000 smolts were stocked annually (Figure 48). This simulation assumed that hatchery smolts would be reared in a semi natural hatchery setting, such that hatchery smolts would suffer only a 35% post-release mortality and would have equal fitness for natural reproduction as that of naturally produce fish. Further, all returning spawners were assumed to spawn naturally. Under these assumptions, any supplementation scenario that resulted in a spawner escapement near 1,400 coho (spawner capacity) would result in natural production of about 290,000 parr, or about 87,000 smolts. This level of natural production would be reached with a constant supplementation of about 150,000 smolts. Given that 35% of hatchery smolts die shortly after release, the surviving number of hatchery smolts would be 97,500. Thus, the contributions of hatchery and natural smolts would be roughly similar.

The simulations with continuous supplementation indicate that natural production could be sustained at full capacity with a stocking rate of about 150,000 smolts annually, given existing conditions. Greater supplementation rates would be required to add harvest in the Grande Ronde Basin, while maintaining full seeding of the habitat for coho parr. These simulations represent a simplistic picture of reality, because they do not incorporate fluctuations in survival between years, which commonly range more than 10-fold (Cramer and Cramer 1994). Given that substantial fluctuations in survival that will occur, one must keep in mind that returns in many years will be much worse than simulated here and much better in other years.

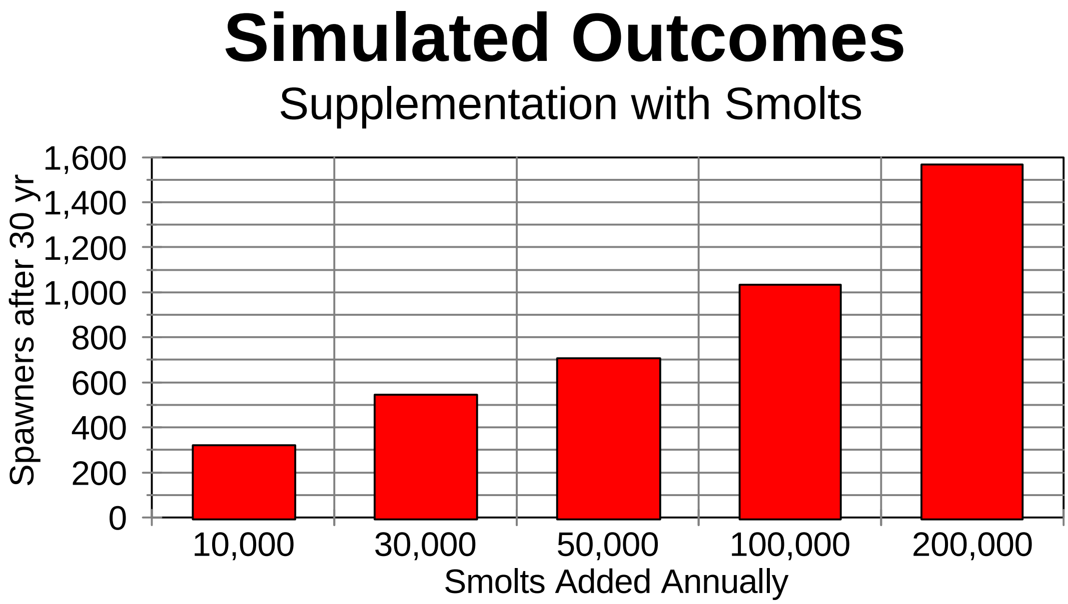


Figure 48 Simulated number of coho spawners returning to Wallowa County after 30 years for various levels of supplementation with smolts, given the "average" scenario (see Table 19) for passage survival and harvest rates.

SUMMARY

We determined that the reintroduction of coho salmon into the Grande Ronde is feasible, but continuous supplementation of hatchery produced coho salmon is necessary to maintain coho populations above eight mainstem dams even with reduced fisheries. Historically, the Grande Ronde Basin produced in excess of 20,000 adult coho salmon annually. Misguided fish culture attempts, excessive harvest, and habitat modifications drastically affected natural coho salmon populations as early as 1912. Hatcheries and artificial fish propagation measures were used on an irregular basis to restore coho salmon population in the Grande Ronde Basin as late as the early-1970's. Coho salmon have been absent from the Basin since the late-1970's.

We examined life history traits of historic and natural populations of coho salmon in the Grande Ronde Basin, and we compared these traits to coho salmon populations in lower Columbia River hatcheries and tributaries. We determined that early-run coho salmon in the Clackamas River are best suited as a coho salmon donor stock in the Grande Ronde Basin. An agreement should be pursued to secure that stock as a donor.

Central and satellite hatchery facilities will be needed to capture adults, incubate eggs, rear juveniles, and acclimate smolts. Location, design and construction of hatchery facilities is needed to implement a coho salmon supplementation program in the Grande Ronde Basin.

Freshwater habitats have changed since coho salmon were abundant in the Grande Ronde Basin. The degree of change in habitat quantity and quality has not been assessed. Habitat surveys should be conducted to develop a more accurate estimate of carrying capacity. Habitat improvement opportunities designed to improve coho salmon production should be identified and implemented. Once the production potential for natural coho salmon has been determined, a plan should be developed which incorporates natural and hatchery production into a coho salmon management plan for each tributary of the Grande Ronde Basin. The Grande Ronde Basin coho salmon management plan should incorporate production and harvest opportunities.

Reintroduction of coho salmon into the Grande Ronde Basin should be guided by adaptive management. Therefore, detailed monitoring and evaluation plans should be designed to measure progress toward goals, as well as identify needs for changes in strategy.

REFERENCES

Allen, R.L. and T.K. Meekin. 1973. Columbia River sockeye salmon study. Progress report. Washington Department of Fisheries.

Anderson, G.A. 1967. Wallowa River fish branding program. Closing Report, Project No. 1585, Columbia River Fisheries Development Program, Ore. State Game, Portland.

Anderson, G. 1969. Construct salmon egg incubation channel on the Wallowa River and evaluate the hatching success with fry traps. Closing Report, Contract no. 14-17-0001-1864, Columbia River Fishery Development Program, Oregon State Game Commission, Portland.

Anderson, J., J. Hayes, P. Shaw, and R. Zabel. 1996. Columbia River Salmon Passage Model (CriSP.1.5) Universtiy of Washington School of Fishereies. Special Publication.

Bartlett, G. 1948. The "Yanks" of the Wallowas. Sunset. May:19-21.

Bartlett, G. 1975. Once, In Wallowa Lake.... Pacific Wilderness Journal. April-May:5-7.

Beacham, T.D., and J.G. McDonald. 1982. Some aspects of food and growth of fish species in Babine Lake, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1057: 23p.

Beattie, W.D., P.T. Clancey, and R. Zubik. 1988. Effect of the operation of Kerr and Hungry Horse dams on the reproductive success of kokanee in the Flathead system. Final report to BPA. Contract DE-AI79-83BP39641, Portland, Oregon

Beauchamp, D.A. 1990. Seasonal and diel food habits of rainbow trout stocked as juveniles in Lake Washington. Transactions of the American Fisheries Society 119:475-482.

Bechtol, W.R. and N.C. Dudiak. 1988. The development of the Leisure Lake sockeye salmon: smolt and adult production summary, 1977 to 1984. Alaska Department of Fish and Game, FRED Reports, No. 83, Juneau.

Bjornn, T.C. D.R. Craddock, and D.R. Corley. 1968. Migration and survival of Redfish Lake, Idaho, sockeye salmon, (Oncorhynchus nerka).

Blackett. 1987. Development and performance of an Alaska steeppass fishway for sockeye salmon (Oncorhynchus nerka). Can.J. Fish. Aquat. Sci. 44: 66-76.

Bowler, B. 1981. Kokanee stock status in Pend Oreille, Priest and Coeur d'Alene Lakes. Job performance report F-73-R-3, Study 6, Job 1, Idaho Department of Fish and Game, Boise.

Bowler, B. 1981b. Kokanee lake systems inventory. Job performance report F-73-R-3, Study 6, Job 2, Idaho Department of Fish and Game, Boise.

Bowles, E.C., E. Rieman, G.R. Mauser, and D.H. Bennett. 1991. Effects of introductions of *Mysis relicta* on fisheries of northern Idaho Am.Fish. Soc.Sym. 9:65-74.

Bowles, E.C. and T. Cochnauer. 1984. Potential sockeye salmon production in Alturas Lake Creek drainage, Idaho. Final Report, prepared for U.S. Forest Service, Sawtooth National Forest, Idaho.

Burgner, R.L. 1987. Factors influencing age and growth of juvenile sockeye salmon (Oncorhynchus nerka) in lakes. p. 129-142. In H.D. Smith, L. Margolis, and D.D. Wood [ed] Sockeye salmon (Oncorhynchus nerka) population biology and future management. Can. Spec. Publ. Fish Aquat. Sci. 96.

Burgner, R.L. 1991. Life history of sockeye salmon, *Oncorhynchus nerka. In:* Pacific salmon life histories, edited by C. Groot and L. Margolis. Univ. B.C. press, Vancouver, B.C.

Carlson, C.D., G. M. Matthews, D.E. Weitkamp, R.P. Whitman, R. Raleigh, and D. Chapman. 1989. Fish transportation studies Priest Rapids Dam 1988. Annual Report, Grant Public Utility District. 26p. + appendix.

Chapman, D.W., W.S. Platts, D.Park, and M. Hill. 1990. Status of Snake River sockeye salmon. Final Report to Pacific Northwest Utilities Conference Committee, 90 p., Portland, Oregon.

Chapman, D.W. and 10 others. 1991. Status of Snake River chinook salmon. Don Chapman Consultants, Report submitted to Pacific Northwest Utilities Conference Committee, Portland.

Clanton, R.E. 1913. Report of Master Fish Warden. In: McAllister, H.C. and R.E. Clanton. 1911. Biennial Report of the Department of Fisheries of the State of Oregon to the Twenty-Sixth Legislative Assembly Regular Session. 90 pp.

Cleaver, F.C. ed. 1951. Fisheries statistics of Oregon. Fish Commission of Oregon, Contribution No. 16, Portland.

Craig, K.M. 1967. Conflicts in the Multiple Use of Wallowa Lake. M.S. thesis. Oregon

State University, Corvallis, Oregon. 82p.

Cramer, S.P. In press. The effect of environmentally-driven variatioin in recruitment on sustainable yield from salmon populations. American Fisheries Society, Proceedings of the Symposium, "Towards sustainable fisheries: balancing the conservation and use of salmon and steelhead in the Pacific northwest."

Cramer, S.P. 1996. Seasonal changes during 1996 in survival of yearling chinook smolts through the Snake River as estimated from detections of PIT tags. S.P. Cramer & Associates, report submitted to Direct Service Industries, Portland, Oregon.

Cramer, S.P. 1996b. Contribution to catch and spawning escapement of salmon produced at Cowlitz Salmon Hatchery and steelhead produced at Cowlitz Trout Hatchery. S.P. Cramer & Associates, report submitted to Tacoma Public Utilities, Tacoma, Washington.

Cramer, D.P. and S.P. Cramer. 1994. Status and population dynamics of coho salmon in the Clackamas River. Portland General Electric Company, Portland, Oregon.

Cramer, S.P., A. Maule, and D. Chapman. 1991. The status of coho salmon in the lower Columbia River. 1991. Don Chapman Consultants, Contract Report submitted to Pacific Northwest Utilities Conference Committee, Portland.

Chapman, D and seven others. 1995. Status of sockeye salmon in the mid-Columbia region. Contract report. BioAnalysts, Inc. Boise, Idaho.

Emlen, J.M., R.R. Reisenbichler, A.M. McGie, and T.E. Nickelson. 1990. Density-dependence at sea for coho salmon (Oncorhynchus kisutch). Can. J. Fish. Aquat. Sci. 47:1765-1772.

Evermann, B.W. and S.E. Meek. 1897. 2.- A Report Upon Salmon Investigations in the Columbia River Basin and Elsewhere on the Pacific Coast in 1896. Bulletin of the United States Fish Commission. 17:15-84.

Fast, D. J. Hubble, M. Kohn, and B. Watson. 1991. Yakima River spring chinook enhancement study. Yakima Indian Nation Fisheries Resource Management, Final Report, to Bonneville Power Administration, Project 82-16, Portland, 345 pp.

Foote, C.J. and P. A. Larkin. 1988. The role of male choice in the assortative mating of anadromous and non-anadromous sockeye salmon (Oncorhynchus nerka). Behavior 106:43-62.

Foote, C. J., C.C. Wood, and R.E. Withler. 1989. Biochemical genetic comparison of sockeye salmon and kokanee, the anadromous and non-anadromous forms of Oncorhynchus nerka. Canadian Journal of Fisheries and Aquatic Sciences 46:149-158.

Gangmark, H.A. and L.A. Fulton. 1952. Status of Columbia River blueback salmon runs, 1951. USFWS, Spec. Sci. Rep. Fish. No. 74., 29 p.

Goldman, C.R., M.D. Morgan, S.T. Threlkeld, and N. Angeli. 1979. A population dynamics analysis of the cladoceran disappearance from Lake Tahoe, California-Nevada. Limnology and Oceanography 24:289-297.

Goodland, J.C., T.W. Gjernes, and E. L. Brannon. 1974. Factors affecting sockeye salmon (Oncorhynchus nerka) growth in four lakes of the Fraser River system. J. Fish. Res. Bd. Can. 31:871-892.

Horner, N., and T.C. Bjornn. 1981. Status of upper Columbia and Snake River coho salmon in relation to the Endangered Species Act. Prepared for the U.S. Fish and Wildlife Service. U. of Idaho, Moscow, Idaho.

Howell, P., D. Jones, D. Scarnecchia, L. LaVoy, W. Kendra, and D. Ortmann. 1985. Stock assessment of Columbia River anadromous salmonids, Volume I: chinook, coho, chum and sockeye salmon stock summaries. Final Report, Bonneville Power Administration, Project no. 83-335, Portland, Oregon.

Hyatt, K.D., and J.G. Stockner. 1985. Responses of sockeye salmon (*Oncorhynchus nerka)* to fertilization of British Columbia coastal lakes. Can. J. Fish. Aquat. Sci. 42:320-331.

Irving, J.S. and T.C. Bjornn. 1981. Status of Snake River fall chinook salmon in relation to the Endangered Species Act. Report prepared for USFWS, Moscow, ID.

Johnson, O.W., T.A. Flagg, D.J. Maynard, G.B. Milner and F.W. Waknitz. 1991. Status review of lower Columbia River coho salmon. NMFS, 2725 Montlake Boulevard East, Seattle, Washington 98112.

Johnson, D.R., W.M. Chapman, and R.W. Schoning. 1948. The effects on salmon populations of the partial elimination of fixed fishing gear on the Columbia Riaver in 1935. Fish Commission of Oregon, Contribution No. 11, 32 p., Clackamas.

Johnson, D.M., and others. 1965. Atlas of Oregon Lakes. Oregon State Univ. Press, Corvallis.

Killick, S.R. 1955. The chronological order of Fraser River sockeye salmon during migration, spawning and death. Internat. Pacific Salmon Fish. Comm., Bull. VII, 95 p.

Killick, S.R. and W.A. Clemens. 1963. The age, sex ratio and size of Fraser River sockeye salmon 1915 to 1960. Internat. Pacific Salmon Fish. Comm., Bull. XIV, 114 p.

Kinsten, B., and P. Olsen. 1981. Impact of *Mysis relicta* Loven introduction on the plankton of two mountain lakes, Sweden. Institue of Freshwater Research Drottningholm Report 59:64-74.

Koenings, J.P. and R. D. Burkett. 1987. Population characteristics of sockeye salmon (Oncorhynchus nerka) smolts relative to temperature regimes, euphotic volume, fry density, and forage base within Alaskan lakes, p. 216-234. In H.D. Smith, L. Margolis, and D.D. Wood [ed] Sockeye salmon (Oncorhynchus nerka) population biology and future management. Can. Spec. Publ. Fish Aquat. Sci. 96.

Kyle, G.B., J.P. Koenings, and B.M. Barrett. 1988. Density-dependent trophic level responses to an introduced run of sockeye salmon (Oncorhynchus nerka) at Frazer Lake, Kodiak Island, Alaska. Can. J. Fish. Aquat. Sci. 45:856-867.

LaBolle, L. 1986. Enhancement of kokanee on Priest and Pend Oreille Lakes. Job performance report, Project F-73-R-7, Idaho Department of Fish and Game, Boise.

Langeland, A. 1981. Decreased zooplankton density in two Norwegian lakes caused by predation by recently introduced *Mysis relicta*. Internationale Vereinigung fur theoretische und angewandte Limnologie Verhandlungen 21:926-937.

Langeland, A. 1988. Decreased zooplankton density in a mountain lake resulting from predation by recently introduced *Mysis relicta.* Internationale Vereinigung fur theoretische und angewandte Limnologie Verhandlungen 23:419-429.

Larson, D.W. 1973. Summer limnological characteristics of glacial moraine Lake Wallowa in northeastern Oregon, 1973. Oregon Department of Environmental Qualtiy, Portland, 50p.

Larson, D.W. 1981. Factors contributing to the maintenance of oligotrophy in an alpine glacial moraine lake (Wallowa Lake) in northeas Oregon. Northwest Science 55:95-107.

Lasenby, D.C., T.G. Northcote, and M. Furst. 1986. Theory, practice, and effects of Mysis relicta introductions to North American and Scandinavian lakes. Can. J. Fish. Aquat. Sci. 43: 1277-1284.

Levy, D.A. 1987. Review of the ecological significance of diel vertical migrations by juvenile sockeye salmon (Oncoryhnchus nerka). In. H.D. Smith, L. Margolis, and C.C. Wood [ed.] Sockeye salmon Oncorhynchyus nerka) population biology and future management. Can. Spec. Publ. Fish . Aquat. Sci. 96.

Lewis, S.L.,and R.B. Lindsay. 1976. Population dynamics of kokanee salmon in Odell Lake. Annual Report, Fish Research Project F-71-R-12, Oregon Department of Fish and Wildlife, Portland.

Lindsay, R.B., W.J. Knox, M.W. Flesher, B.J. Smith, E.A. Olsen, and L.S. Lutz. 1986. Study of wild spring chinook salmon in the John Day River system. Oregon Department of Fish and Wildlife, Final Report to Bonneville Power Administration, Project 79-4. Portland, 119 pp.

Lister, D. B., L. M. Thorson, and I. Wallace. 1981.Chinook and coho salmon escapements and coded-wire tag returns to the Cowichan-Koksilah river system, 1976-1979. Can. Manuscript Rep. Fish. Aquat. Sci. 1608, 168p.

Lindsay, R.B. and S. L. Lewis. 1975. Population dynamics of kokanee salmon in Odell Lake. Oregon Department of Fish and Wildlife, Research Division, Kokanee Population Dynamics, Job Prog. Rept F-71-R-11, Jobs 10 and 11. 12pp.

Lindsay, R.B. and S. L. Lewis. 1978. Lake and reservoir investigations (kokanee ecology). Final report, Fish research project F-71-R, Oregon Department of Fish and Wildlife, Portland.

Martinez, P.J. 1986. Zooplankton and kokanee interactions in Lake Granby, Colorado, and management of introduced *Mysis.* Master's thesis. Colorado State University, Fort Collins.

Matson, 1958. Preliminary report, Wallowa Lake blueback salmon rehabilitation project. Mimeographed report, Fish Commission of Oregon, Portland.

Mauser, G.R. , R.W. Vogelsang, and C.L. Smith. 1988. Enhancement of trout in large north Idaho lakes. Job Performance Report, Lake and Reservoir Investigations, Project F-73-R-9, Idaho Department of Fish and Game, Boise.

Maynard, D.J., T.A. Flagg, C.V.W. Mahnken. 1995. A review of seminatural culture strategies for enhancing the postrelease survival of anadromous salmonids. American Fisheries Society Symposium 15:307-314.

McAllister, H.C. 1909. Report of Master Fish Warden. 42 p. In: McAllister, H.C. and R.E. Clanton. 1911. Biennial Report of the Department of Fisheries of the State of

Oregon to the Twenty-Sixth Legislative Assembly Regular Session. 90 pp.

McDonald, J. 1969. Distribution, growth, and survival of sockeye fry (Oncorhynchus nerka) produced in natural and artificial stream environments. J. Fish. Res. Bd. Can. 26:229-267.

McGuire, H.D. 1898. Fifth and Sixth Annual Reports of the Fish and Game Protector of the State of Oregon. 1897-1898. 142 p.

Morgan, M.D., S.T. Threlkeld, and C.R. Goldman. 1978. Impact of the introduction of kokanee *(Oncorhynchus nerka)* and opossum shrimp *(Mysis relicta)* on a subalpine lake. J. Fish. Res. Bd. Can. 35:1572-1579.

Muir, W.D. and ten others. 1995. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1994 . Annual Report to Bonneville Power Administration, Portland, Oregon Contract DE-AI79-93BP10891.

Mullan, J.W. 1984. Overview of artificial and natural propagation of coho salmon *(Oncorhynchus kisutch)* on the mid-Columbia River. U.S. Fish and Wildlife Service, Report No. FRA/FAO-84-4, Leavenworth, Washington, 37p.

Mullan, J.W. 1986. Determinants of sockeye salmon abundance in the Columbia River, 1880's-1982: a review and synthesis. U.S. Fish and Wildlife Service, Biological Report 86(12),136p., Leavenworth, Washington.

Mullen, R.E. 1981. Oregon's commercial harvest of coho salmon, Oncorhynchus kisutch (Walbaum), 1892-1960. Oregon Department of Fish and Wildlife, Information Report Series, Fisheries No. 81-3.

Nero, R.W., and W.G. Sprules. 1986. Predation by three glacial opportunists on natural zooplankton communities.Can J. Zoo. 64:57-64.

NMFS (National Marine Fisheries Service). 1992. 1992 Operation of the federal Columbia River power system. Endangered Species Act, Section 7 consultation/conference, biological opinion. National Marine Fisheries Service, Northwest Region. Portland, Oregon.

Northcote, T.G. 1967. The relation of movements and migrations to production in freshwater fishes, p. 315-344. In S.D. Gerking [ed.] The biological basis of freshwater fish production. Blackwell Scientific Publications, Oxford, U.K.

Northcote, T.G. 1972. Some effects of mysid introduction and nutrient enrichment on a large oligotrophic lake and its salmonids. Internationale Vreinigung fuer

Theoretische und Angewandte Limnologie Verhandlungen 28:1096-1106

Northcote, T.G. 1991. Successes, problems, and control of introduced nysid populations in lakes and reservoirs. Am.Fish. Soc. Sym. 9:5-16.

Northwest Power Planning Council (NPPC). 1989. Salmon and steelhead system planning documentation. Prepared by the Monitoring and Evaluation Group.

Olson, F.W. 1984. Vertical distribution of juvenile salmonids entering the turbine intakes at Wanapum Dam. CH2MHill report to Public Utility District of Grant County, Washington.

Oregon Department of Fish and Wildlife (ODFW). 1982. Comprehensive plan for production and management of Oregon's anadromous salmon and trout. Part II. Coho salmon plan. Oregon Department of Fish and Wildlife, Portland

Oregon Department of Fish and Wildlife(ODFW) and Washington Department of Fisheries (WDF). 1988. Status report, Columbia River fish runs and fisheries, 1960-88. Oregon Department of Fish and Wildlife, Portland.

Oregon Department of Fish and Wildlife(ODFW) and four others. 1989. Draft Grande Ronde River Subbasin salmon and steelhead production plan. Columbia Basin System Planning, Northwest Power Planning Council, Portland, Oregon.

Oregon Department of Fish and Wildlife (ODFW) and four others. 1990. Grande Ronde River Subbasin, salmon and steelhead production plan. Columbia Basin System Planning, Northwest Power Planning Council, Portland, Oregon.

Pacific Fisheries Management Council (PMFC). 1990. Review of 1989 ocean salmon fisheries. Portland, Oregon.

Park, D.L. and W.W. Bentley. 1968. A summary of the 1967 outmigration of juvenile salmonids in the Columbia Basin. Progress Report, U.S. Bureau of Commercial Fisheries, 14 p., Seattle, Washington.

Park, D.L. 1980. Transportation of chinook salmon and steelhead smolts 1968-80 and its impact on adult returns to the Snake River. Progress report, Natl. Mar. Fish. Serv., Seattle, Washington. 20p.

Parkhurst, Z.E.. 1950. Survey of the Columbia River and its tributaries, Part VI. Area 5, Snake River system from the mouth through the Grande Ronde River. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 40, 95p.

Petrosky, C.E. 1990. Estimating spring chinook parr and smolt abundance in wild and natural production areas. pp. 57-61. IN: D. Park, Convener, Status and future of spring chinook salmon in the Columbia River basin -- conservation and enhancement. Spring chinook Salmon Workshop, 8-9 November, 1989, Pasco Washington, sponsored by the National Marine Fisheries Service. 130 pp.

Pratschner, G.A. 1978. The relative resistance of six transferrin phenotypes of coho salmon *(Oncorhynchus kisutch)* to cytophagosis, furunculosis, and vibriosis. M.S. Thesis, Univ. Washington, Seattle, 71p.

Raymond, H.L. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966 to 1975. Trans. Am. Fish. Soc. 108(6):505-529.

Raymond, H.L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer chinook salmon and steelhead in the Columbia River Basin. North Am. J. Fish. Managmnt. 8:1-23

Reed, F.C. 1901. Annual Reports of the Department of Fisheries of the State of Oregon to the Legislative Assembly, Twenty-First Regular Assembly. 142 p.

Reeves, G.H, F.H. Everest, and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. Gen. Tech. Rep. PNW-GTR-245. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 18p.

Reisenbichler, R.R. 1988. Relation between distance transferred from natal stream and recovery rate of hatchery coho salmon. N. Am. J. Fish. Mgt. 8:172-174.

Richards, R.C., C.R. Goldman, T.C. Frantz, and R. Wickwire. 1975. Where have all the *Daphnia* gone? The decline of major cladoceran in Lake Tahoe, California-Nevada. Internationale Vereinigung fur theoretische und angewandte Limnologie Verhandlungen 19:834-842.

Ricker, W.E. 1938. “Residual” and kokanee salmon in Cultus Lake. J. Fish. Res. Board Can. 4:192-217.

Ricker, W.M. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin 191, Ottawa.

Rieman, B. E., B. Bowler, J. r. Lukens, and P. F. Hassemer. 1979. Priest Lake fisheries investigations. Job performance report, Project F-73-R-1, Lake and Reservoir Investigations, Idaho Department of Fish and Game, Boise.

Rieman, B. E. and D.B. Meyers. 1990. Status and analysis of salmonid fisheries, Kokanee population dynamics. Idaho Department of Fish and Game, Job performance report, Project F-73-R-12, Boise.

Rieman, B.E. and C.M.Falter. 1981. Effects of the establishment of Mysis relicta on the macrozooplankton of a large lake. Trans. Am. fish. Soc. 110:613-620.

Rieman, B.E. 1981. Kokanee-zooplankton interactions and description of carrying capacity. Job performance report, Project F-73-R-3, Study 6, Job 5, Idaho Department of Fish and Game, Boise.

Rieman, B.E., and B. Bowler. 1980. Trophic ecology of kokanee and limnology in Pend Oreille Lake, Idaho. Dept. Fish and Game Fish. Bull. 1, Boise.

Rieman, B.E. 1981b. Kokanee early life history and enhancement evaluation. Job performance report, Project F-73-R-3, Study 6, Job 4, Idaho Department of Fish and Game, Boise.

Rieman, B.E., and C.M. Falter.1981.Effects of the establishment of *Mysis relicta* on the macrozooplankton of a large lake.Trans.Amer.Fish. Soc110:613-620.

Riggle, D. 1983. 35 years on Smith Mountain. Baker Printing & Lithography, Baker, Oregon, 52 p.

Rogers, D.E. 1984. Trends in abundance of northeastern Pacific stocks of salmon, p. 100-127. *In:* W.G. Pearcy (ed.). The influence of ocean conditions on the production of salmonids in the North Pacific. Oreg. State Univ. Sea Grant Coll. Program, ORESU-W-83-001.

Sandercock, F. K.1991. Life history of coho *(Oncorhynchus kisutch)*. *In* C. Grott and L. Margolis (editors), Pacific salmon life histories, P. 396-445. Univ. British Columbia Press, Vancouver.

Stout, W.H. and R.L. Swan. 1967. Opossum shrimp collection - 1967. Oregon State Game Commission, Fishery Division, Habitat Improvement Project, Number 23, Portland.

Suzumoto, B.K., C.B. Schreck, and J.D. McIntyre. 1977. Relative resistance of three transferrin genotypes of coho salmon *(Oncorhynchus kisutch)* and their hematological responses to bacterial kidney disease. J. Fish. Res. Board Can. 34(1):1-8.

Swartzman, G.L. and D. A Beauchamp. 1990. Simulation of the effect of rainbow trout introduction in Lake Washington. Trans. Am. Fish. Soc. 119:122-134.

Thompson, R.N. and J.B. Haas. 1960. Environmental survey report pertaining to salmon and steelhead in certain rivers of eastern Oregon and the Willamette River and its tributaries: Part 1. survey reports of eastern Oregon rivers. Fish Commission of Oregon, Clackamas.

Thorne, R.E. and J.J. Ames. 1987. A note on variability of marine survival of sockeye salmon (Oncorhynchus nerka) and effects of flooding on spawning success. Can. J. Fish. Aquat. Sci. 44:1791-1795.

Toner, R.C. 1960. A study of some of the factors associated with the reestablishment of blueback salmon (Oncorhynchus nerka) into the upper Wallowa River System. A1-A46. In: Thompson, R.N. and J.B. Haas. 1960. Environmental Survey Report Pertaining to Salmon and Steelhead in Certain Rivers of Eastern Oregon and the Willamette River and its Tributaries. Part 1. Survey Reports of Eastern Oregon Rivers. Fish Commission of Oregon, Research Division, Clackamas, Oregon. 432 p.

U.S. Army Corps of Engineers (USACE).1948-1990. Annual fish passage report, Columbia River projects. U.S.Army Corps of Engineers, Portland, Oregon.

Utter, F.M., D. Compton, S. Grant, G. Milner, J. Seeb, and L. Wishard. 1980. Population structures of indigenous salmonid species of the Pacific Northwest. In: Salmonid ecosystems of the North Pacific, W.J. McNeil and C.D. Himsworth (eds.), Or. St. Univ. Press, Corvallis, pp. 165-170.

VanDusen, H.G. 1905. Annual Reports of the Department of Fisheries of the State of Oregon for the years 1903 and 1904 to the Twenty-Third Legislative Assembly [Regular Session]. 183 p.

VanDusen, H.G. 1907. Annual Reports of the Department of Fisheries of the State of Oregon for the years 1903 and 1904 to the Legislative Assembly, Twenty-Fourth Regular Session. 197 p.

VanDusen, H.G. 1903. Annual Reports of the Department of Fisheries of the State of Oregon for the years 1901 and 1902 to the Twenty-Second Legislative Assembly [Regular Session]. 183 p.

Waples, R.S. 1991. Pacific salmon, *Oncorhynchus* spp., and the definition of “species” under the Endangered Species Act. U.S. Natl. Mar. Fish. Serv. Mar. Fish. Rev. 53(3):11.22.

Ward, N.W. 1996. Mitochondrial DNA variation among Clackamas River coho salmon populations. Oregon State University, OCFRU Genetics Laboratory Report 96(3), 22 pp, Corvallis.

Washington Department of Fisheries and Wildlife and Oregon Department of Fish & Wildlife and (WDFW and ODFW). 1996. Status report Columbia River fish runs and fisheries 1938-95. Oregon Department of Fish and Wildlife, Clackamas, Oregon.

Washington Department of Fisheries (WDF) and three others. 1989. Draft Wenatchee River Subbasin salmon and steelhead production plan. Columbia Basin System Planning, Northwest Power Planning Council, Portland, Oregon.

Weitkamp, L.A., T. C. Wainwright, G.J. Bryant, G. B. Milner, D.J. Teel, R.G. Kope, and R.S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U. S. Dep. Commer, NOAA Tech. Memo. NMFS-NWFSC-24, 258p.

Zyblut, E.R. 1970. Long term changes in the limnology and macrozooplankton of a large British Columbia Lake. J. Fish. Res. Bd. Can. 27:1239-1250.

APPENDICES

Appendix 1. Reports perused for historic data on salmon in the Grande Ronde basin.

Oregon State Board of Fish Commissioners. Annual reports to the Governor of Oregon. (1887-92)

Oregon Fish and Game Protector. Annual reports. (1893-98)

Oregon State Board of Fish Commissioners. Annual reports of the Oregon Department of Fisheries (by the) Master Fish Warden. (1899-1912).

Oregon State Board of Fish and Game Commissioners. Biennial reports. (1911-20). (Requested 1911-16 for loan 9/7/90)

Oregon Fish Commission. Biennial reports to the Governor and the Legislative Assembly. (1920-74). (Requested 1919-30 for loan 8/7/90)

Oregon Fish Commission. Biennial reports to the Governor and the Legislative Assembly. (1920-74).

Oregon Game Commission. Annual district reports to the Chief of Fisheries.
1956-59 Northeastern Oregon
1960-71 La Grande District
1964-88 Wallowa District

Oregon Department of Fish and Wildlife. Biennial reports. (1974-present).

Appendix 2. Chronology of events influencing sockeye or kokanee in Wallowa Lake.

1875 white settlers (Toner 1960, pg. 7).

1877 Wallowa Nez Perce Indians forced to the reservation in Idaho (Bartlett 1975, pg. 5).

1880 first water right obtained by Mitchell Ditch Co. for irrigation (Toner 1960, pg. 33).

1881-82 2 canneries operated -- tot. annual catch 60,000 lbs./yr.; shipping too costly to continue (Bartlett 1948, pg. 19; Bartlett 1975, pg. 7); James McCall cannery established prior to 1894, in operation 4-5 yrs. (Toner 1960, pg. 8).

1882 first major diversion right by Joseph Light and Power Co. and Joseph Milling Co. (Toner 1960, pg. 33).

1883 'The run of redfish was very large' (Evermann and Meek 1897, pg. 25).

1884 rough dam built to service nearby shingle mill (Bartlett 1975, pg. 7; Johnson, et. al. 1985, pg. 140); 'It is estimated that less than 100 redfish entered the lake.' (Evermann and Meek 1897, pg. 25).

1885 'About 75 were caught with a seine, the run being very small.' (Evermann and Meek 1897, pg. 25).

1886 'The run was very large, but not as large as in 1883.' (Evermann and Meek 1897, pg. 25).

1887-89 'Very few redfish were caught with spears in the river above the lake.' (Evermann and Meek 1897, pg. 25).

1890 heavier dam built and irrigation ditch laid out (Bartlett 1975, pg. 7; Johnson, et. al. 1985, pg. 140); first comments on problem of fish descending unscreened ditches (Toner 1960, pg. 8); 'The run was quite large; two parties salted many for the home market.' (Evermann and Meek 1897, pg. 25); Grande Ronde river at La Grande "thick with mud, from the effects of mining above, it was impossible to see a fish; therefore,... if the mining operations go on all summer, we don't think the fish will go up, it is doubtful if they could live in its muddy waters (Oregon State Board of Fish Commissioners 1889, pg. 19).

1891-93 'Very few redfish seen in the lake during these years.' (Evermann and Meek 1897, pg. 25).

1894 'About 2,000 redfish were caught at the head of the lake and salted.' (Evermann and Meek 1897, pg. 25); largest run of sockeye in Columbia ever known since inception of canning industry - marked decline in fish numbers since (McGuire 1898, pg. 86).

1895 'The run was again very small.' (Evermann and Meek 1897, pg. 25); unscreened ditches called to the attention of the "Fish and Game Protector" (McGuire 1896, pg. 53).

1896 'The run was very small; about one dozen were seen in the lake and one in the inlet.' (Evermann and Meek 1897, pg. 25).

1899 'no bluebacks entered lake this season, and, in fact, there had been very few since 1895 (Reed 1901, pg. 8).

1903 Wallowa River Hatchery established 40 mi. downstream from Wallowa Lake; Grande Ronde River Hatchery Station at mouth of Wenaha closed because of moss and inability to acquire title to land and rights (VanDusen 1905, pg. 44); Grande Ronde River Hatchery re-established couple mi. up Wenaha River (Van Dusen 1905, pg. 97); 1342 female sockeye spawned at Wallowa River Hatchery (VanDusen 1905, pg. 46).

1904 'blueback extinct due to unscreened irrigation ditches downstream' (Toner 1960, pg. 9); Wallowa Hatchery not operated due to lack of funds and no egg rearing building (Van Dusen 1905, pg. 96).

1905 dam raised lake 4' (Craig 1967, pg. 13); "dam built quite low and did not prevent blueback salmon from passing in and out of lake"; sightings of bluebacks 0.75 mi. below Minam when dam was built (Toner 1960, pg. 9); stocks practically eliminated as early as 1905, however, "it is believed that small numbers of adults frequented the Wallowa Lake spawning ground up until 1916" (Toner 1960, pg. 10); fish rack June 27 - Dec. 10 -- no sockeye at Wallowa Hatchery, previous years migrate up Sept.-Oct. (Van Dusen 1907, pg. 78).

1906 dam enlarged (Toner 1960, pg. 9); about 1906 Wallowa River Hatchery dam built - "log-crib structure, filled with rock, 117' long, 14' high above low-water mark which stopped ascending salmon" (McAllister 1909, pg. 24).

1907 blueback salmon in Columbia decreased greatly from an unhindered commercial catch of adults over the years (Van Dusen 1909, pg. 11); Wallowa Hatchery dam vandalized with dynamite - minimal effect on effectiveness of dam, although there was still no fish (McAllister 1909, pg. 84).

1908 screen was constructed across lake to inhibit loss of fish to irrigation ditches "although it is said that some fish still escaped"; life history of fish not understood (Bartlett 1975, pg. 7). According to Craig (1967, pg. 28), dam and screen constructed 1905.

1909 "salmon are now diverted to other streams before reaching the Wallowa"; amount of spawn taken at Wallowa Hatchery small (McAllister 1909, pg. 26).

1916 concrete dam constructed (Toner 1960, pg. 7); 18' above bottom of sill gates (Craig 1967, pg. 13); construction of larger dam for power generation terminated runs permanently (Johnson, et.al. 1985, pg. 140).

1920 dam raised additional 3' to overall height of 21' (Craig 1967, pg. 14); sightings of juvenile bluebacks in irrigation ditches (Toner 1960, pg. 9).

1929 dam raised additional 6' to present overall height of 26.8' (Craig 1967, pg. 14; Toner 1960, pg. 10).

1946 study of Wallowa Lake started in spring, plan to block all tribs. and stock only with hatchery-reared fish (B.R.G.C. 1947).

1948 State Park established (Craig 1967, pg. 28).

1950 Oregon State Highway Commission channelized 1.25 mi. of stream at head of lake to control flooding which resulted in a drastic reduction in natural spawning area; while there was once a maze of small channels, now there exists only one main channel (plus two of original spawning channels that were opened later by Oregon Game Commission for utilization by kokanee) (Toner 1960, pg. 15).

1951 "It is our impression that the present screen was built by the Game Commission with W.P.A. [Works Progress Administration (?)] labor" (Letter from Ore. State Game Comm. to Pacific Power and Light Co., 7/9/51).

1955 several preliminary investigations into reestablishing Sockeye into Wallowa Lake began (Toner 1960 pg. 7).

1956 letter indicates that screens are damaged and has allowed substantial escapement of fish (Inter-Office Correspondence, State Game Commission, 10/13/56); auxiliary power plant at Joseph abandoned (Craig 1967, pg. 24).

1957 "the defunct Wallowa Lake stationary fish screen has been removed from the lake outlet" (Sayre 1957, pg.2).

1958 survey concludes "limited spawning area in lake due to steep moraines and silting of gravel"; northwest corner of lake is utilized for spawning by kokanee during fall (Toner 1960, pg. 12).

1959 "It is possible that screening of openings would not be necessary" (Thompson 1959, pg. 2); 2 fish traps, Silver Lake Ditch and Farmers Ditch, in operation May 25 - Aug. 31 (one dead kokanee) (Toner 1960, pg. 43).

1960 25 unscreened irrigation diversions between outlet and Rock Creek; Oregon Game Commission interested in screening 21 of these; "all ditches found to be containing fish will probably be screened in next 2-3 yrs."; Ore. Game Comm. preparing work schedule (Toner 1960, pg. 30); excellent spawning beds extending 1.5 mi. in west fork 6 mi. from E/W fork junction (Toner 1960, pg. 15); pollution from log pond in short length of river about 0.25 mi. downstream of Mount Emily Lumber Co. (Toner 1960, pg. 33).

1967 many ditches have been screened except the larger ones from 10 to 30 feet wide; Silver lake, Consolidated and Farmer ditches have not been screened because of their size, volume, and cost of construction (Craig 1967, pg. 34).

Appendix 3. Timing of sockeye spawning in the Wallowa River. Data are number of females spawned.

Date	1902	1903	Date	1902	1903
12-Oct			01-Nov		
13-Oct	11		02-Nov		29
14-Oct	10		03-Nov		56
15-Oct	19		04-Nov		64
16-Oct	12	21	05-Nov		54
17-Oct	24		06-Nov		204
18-Oct	36		07-Nov		186
19-Oct		10	08-Nov		62
20-Oct	57	22	09-Nov		57
21-Oct	38	10	10-Nov		31
22-Oct	41	18	11-Nov		8
23-Oct	87	17	12-Nov		21
24-Oct	78	21	13-Nov		55
25-Oct	89	28	14-Nov		38
26-Oct	74	31	15-Nov		74
27-Oct	110	36	16-Nov		
28-Oct	142	49	17-Nov		
29-Oct	153	104	18-Nov		
30-Oct	71	18	19-Nov		
31-Oct	121	18			
			Total females	1,173	1,342
			Total eggs	3,654,000	3,901,000
			Eggs/female	3,115	2,907
Notes:				a,c	b

a. Grande Ronde Station at Troy
b. Wallowa Station at Minam
c. 5 million additional eggs taken but no room in hatchery. Planted in Grande Ronde below racks. Estimate 2,778 females @ 3,115 eggs.
d. 1898 report of Fish and Game Protector - ave. wt 4.5 lbs
e. run passes Troy between June 20 and July 20 1901
f. First salmon reached racks July 15. Continue gradually to spawning.

Appendix 4. Angler effort and harvest in Wallowa Lake during stratum 1 (Approximately April 20 to May 7).

	Boat					Bank							
Year	Angler Hours	# of Rainbow	Rainbow per hour	# of Kokanee	Kokanee per hour	Angler Hours	# of Rainbow	Rainbow per hour	# of Kokanee	Kokanee per hour	Boat hrs per day	Bank hrs per day	Stratum Days
1965	2870	1090	0.38	130	0.05	1050	590	0.56	0	0.00	205.00	75.00	14
1966	1058	425	0.40	4	0.00	3546	3406	0.96	58	0.02	75.57	253.29	14
1967	870	470	0.54	40	0.05	3025	4428	1.46	10	0.00	54.38	189.06	16
1968	324	310	0.96	66	0.20	1687	1927	1.14	14	0.01	18.00	93.72	18
1969	634	677	1.07	283	0.45	2400	3223	1.34		0.00	33.37	126.32	19
1970	344	674	1.96		0.00	2088	3364	1.61		0.00	17.20	104.40	20
1971	80	82	1.03		0.00	1770	3622	2.05	710	0.40	5.33	118.00	15
1972	268	308	1.15		0.00	1792	4272	2.38		0.00	26.80	179.20	10
1973													
1974													
1975													
1976	260		0.00		0.00	2220	2350	1.06		0.00	17.33	148.00	15
1977	1906	770	0.40		0.00	6344	3640	0.57		0.00	119.13	396.50	16
1978	925	465	0.50		0.00	4318	4761	1.10		0.00	54.41	254.00	17

Appendix 5. Angler effort and harvest in Wallowa Lake during stratum 2, (approximately May 8-June 30).

	Boat					Bank							
Year	Angler Hours	# of Rainbow	Rainbow per hour	# of Kokanee	Kokanee per hour	Angler Hours	# of Rainbow	Rainbow per hour	# of Kokanee	Kokanee per hour	Boat hrs per day	Bank hrs per day	Stratum Days
1965	14690	4770	0.32	3820	0.26	7600	5660	0.74	0	0.00	267.09	138.18	55
1966	12065	4147	0.34	12023	1.00	7549	7280	0.96	650	0.09	219.36	137.25	55
1967	15529	889	0.06	17050	1.10	4326	2772	0.64	158	0.04	287.57	80.11	54
1968	10050	2904	0.29	10450	1.04	3312	2347	0.71	152	0.05	186.11	61.33	54
1969	8450	1956	0.23	12680	1.50	1802	771	0.43	125	0.07	156.48	33.37	54
1970	8350	3387	0.41	9203	1.10	5671	4582	0.81	1402	0.25	154.63	105.02	54
1971	5420	2350	0.43	3868	0.71	4977	3018	0.61	320	0.06	102.26	93.91	53
1972	13940	4077	0.29	18424	1.32	6328	4372	0.69	378	0.06	263.02	119.40	53
1973	15622	4099	0.26	29937	1.92	6763	5613	0.83	31	0.00	300.42	109.06	52
1974	15622	4099	0.26	20037	1.28	4962	1840	0.37	821	0.17	294.75	93.91	53
1975	14781	3000	0.20	16871	1.14	7460	6165	0.83	406	0.05	314.49	134.64	47
1976	16415	2969	0.18	30645	1.87	6983	5405	0.77	1366	0.20	309.72	131.75	53
1977	16777	5128	0.31	20030	1.19	11870	7944	0.67	672	0.06	316.55	223.96	53
1978	14589	4184	0.29	10984	0.75	8701	5885	0.68	521	0.06	275.26	164.17	53
1979	17609	3410	0.19	27848	1.58	5330	2606	0.49	59	0.01	374.66	113.40	47
1980	14148	1702	0.12	18892	1.34	4357	3840	0.88	50	0.01	301.02	92.70	47
1981	8978	2096	0.23	9270	1.03	3786	2521	0.67		0.00	191.02	80.55	47
1982	21242	4241	0.20	30592	1.44	2376	2278	0.96	31	0.01	451.96	50.55	47
1983	13035	3649	0.28	21285	1.63	2326	2603	1.12	128	0.06	277.34	49.49	47
1984	26142	7050	0.27	31195	1.19	4161	4265	1.02	136	0.03	502.73	80.02	52
1985													0
1986	19736	3796	0.19	24828	1.26	3181	1748	0.55	28	0.01	328.93	53.02	60
1987	21167	643	0.03	21687	1.02	1793	373	0.21		0.00	347.00	29.39	61
1988	15664	2816	0.18	14488	0.92	3258	3173	0.97	7	0.00	256.79	53.41	61
1989	21200	3334	0.16	17198	0.81	4266	2877	0.67	27	0.01	347.54	69.93	61
1990	13632	2590	0.19	10742	0.79	5013	3904	0.78	35	0.01	223.48	82.18	61

Appendix 6. Angler effort and harvest in Wallowa Lake during stratum 3, (approximately July 1-September 15).

	Boat					Bank							
Year	Angler Hours	# of Rainbow	Rainbow per hour	# of Kokanee	Kokanee per hour	Angler Hours	# of Rainbow	Rainbow per hour	# of Kokanee	Kokanee per hour	Boat hrs per day	Bank hrs per day	Stratum Days
1965	9190	4820	0.52	1240	0.13	3440	2090	0.61	0	0.00	119.35	44.68	77
1966	20580	8962	0.44	227	0.01	5597	1797	0.32	0	0.00	274.40	74.63	75
1967	27324	18866	0.69	492	0.02	1432	462	0.32	0	0.00	364.32	19.09	75
1968	14900	6586	0.44	4177	0.28	3968	1476	0.37	20	0.01	198.67	52.91	75
1969	13240	4960	0.37	3765	0.28	2420	930	0.38		0.00	176.53	32.27	75
1970	31443	19572	0.62	3409	0.11	2188	474	0.22		0.00	408.35	28.42	77
1971	29216	18150	0.62	1457	0.05	3977	752	0.19	540	0.14	379.43	51.65	77
1972	17901	9438	0.53	1044	0.06	3699	1792	0.48	21	0.01	232.48	48.04	77
1973													
1974													
1975													
1976	19949	5010	0.25	640	0.03	3215	650	0.20	211	0.07	259.08	41.75	77
1977	10443	4079	0.39	2586	0.25	3883	875	0.23	146	0.04	135.62	50.43	77
1978	14935	5863	0.39	757	0.05	3404	1169	0.34	18	0.01	193.96	44.21	77
1979													
1980													
1981													
1982													
1983													
1984													
1985													
1986													
1987	13600	7077	0.52	528	0.04	2864	654	0.23		0.00	219.35	46.19	62
1988	16866	10536	0.62	890	0.05	3514	1457	0.41		0.00	272.03	56.68	62
1989													
1990	15428	6365	0.41	1504	0.10	4684	1682	0.36	4	0.00	248.84	75.55	62

Appendix 7. Angler effort and catch in Wallowa Lake during stratum 4, (approximately September 16-October 31).

	Boat					Bank							
Year	Angler Hours	# of Rainbow	Rainbow per hour	# of Kokanee	Kokanee per hour	Angler Hours	# of Rainbow	Rainbow per hour	# of Kokanee	Kokanee per hour	Boat hrs per day	Bank hrs per day	Stratum Days
1965													
1966	874	920	1.05	0	0.00	552	125	0.23	7	0.01	19.00	12.00	46
1967													
1968						204		0.00		0.00	0.00	4.43	46
1969						544	99	0.18		0.00	0.00	11.83	46
1970	396		0.00		0.00	330	254	0.77		0.00	8.61	7.17	46
1971	1078	368	0.34		0.00	700	460	0.66		0.00	23.43	15.22	46
1972	648	803	1.24		0.00	397	458	1.15		0.00	14.09	8.63	46
1976	640	64	0.10		0.00						13.91	0.00	46
1977	552	966	1.75		0.00	920	322	0.35		0.00	12.00	20.00	46
1978	980	28	0.03		0.00	1016	720	0.71		0.00	21.30	22.09	46

Appendix 8. Fish stocked in Wallowa Lake and sockeye stocked in the Wallowa River, 1903-1989.

Year	Species	No.	Wt.	Size	Date	Origin	Hatchery	Area of Release	Reference
1902	sockeye	3,288,000		fry					
1902	sockeye	5000000		eggs	November				
1903	sockeye	3,901,000		eggs	10/13-11/15/03	Wallowa River	Wallowa	Wallowa River	A.R.D.F. 1905
1922	sockeye	467,000		7 mos.			Wallowa	Wallowa River	B.R.F.C. 1923
1924	sockeye	5,054,230		fry			Wallowa	Wallowa River	B.R.F.C. 1925
1925	sockeye	3,483,700		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1927
1925	yanks	246,700		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1927
1925	yanks	400,000		fry		Wallowa Lake		Wallowa Co.	B.R.G.C. 1926
1926	sockeye	3,438,900		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1927
1926	yanks	2,196,900		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1927
1926	yanks	300,000		fingerlings			Wallowa	Wallowa Lake	B.R.F.C. 1927
1929	yanks	312,942		fry			Union	Wallowa Co.	B.R.G.C. 1931
1929	*blueback	146,000		2", 10 mos.			Wallowa	Wallowa River	B.R.F.C. 1931
1930	yanks	813,000		fry		Wallowa Lake	Union	Wallowa Co.	B.R.G.C. 1931
1930	*blueback	500,000		3", 11 mos.			Wallowa	Wallowa River	B.R.F.C. 1931
1930	*blueback	199,200		4.5", 16 mos.			Wallowa	Wallowa River	B.R.F.C. 1931
1931	*blueback	3,574,400		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1933
1932	yanks	4,178,500		fry			Wallowa	Wallowa Co.	B.R.G.C. 1932
1932	**blueback	1,426,000		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1933
1933	blueback	29,000		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1935
1934	yanks	244,000					Wallowa	Wallowa Co.	B.R.G.C. 1934
1935	blueback	662,000		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1937
1936	blueback	1,005,000		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1937
1937	blueback	1,070,700		fingerlings			Wallowa	Wallowa River	B.R.F.C. 1939
1938	yanks	1,528,000				Wallowa Lake	Wallowa	Wallowa Lake	B.R.G.C. 1938
1939	yanks	64,000		0-2		Wallowa Lake	Wallowa	Wallowa Lake	B.R.G.C. 1940
1940	yanks	334,733		0-2		Wallowa Lake	Wallowa	Wallowa Lake	B.R.G.C. 1940
1941	yanks	9	3.00	7"-20",9.5		Wallowa Lake		Wallowa Lake	B.R.G.C. 1942
1942	yanks	294,518		0-2				Wallowa Lake	ODFW files
1942	yanks	326,954	466.00					Wallowa/Union Co.	B.R.G.C. 1942
1947	yanks	180,800	56.80	0-2	03-08-14-19		Wallowa	Wallowa Lake	B.R.G.C. 1948
1948	yanks	219,200	68.80	0-2	04-19-30-31		Wallowa	Wallowa Lake	B.R.G.C. 1948
1950	yanks	341,200	109.80	0-2				Wallowa Lake	ODFW files
	RB	100,138	665.00	2.5"	July				ODFW files
	RB	35,377	3,085.00	6.0"	April				ODFW files
	RB	12,750	510.00	4.5"	October				ODFW files
	RB	961	588.00	10+"	April				ODFW files
1951	RB	35,655	3,435.00	6.3"	April, May				ODFW files
1952	RB	30,454	4,406.00	7.2"	April				ODFW files
1953	kokanee	19,750						Wallowa Lake	ODFW files
	RB	30,314	5,025.00	6.2"	April				ODFW files
1954	kokanee	128,340	30.00	-1"	03-16-54		Wallowa	Wallowa Lake	ODFW files
	RB	57,528	10,052.00	7.1"					ODFW files
1955	kokanee	135,473	67.80	0-2	06-15-55	Montana	Wallowa	Wallowa Lake	ODFW files
	RB	45,386	5,815.00	6.9"	Apr-Jul, Sep., Nov.				ODFW files

Year	Species	No.	Wt.	Size	Date	Origin	Hatchery	Area of Release	Reference
1956	kokanee	92,920	20.00	unfed fry	05-09-56	Montana	Wallowa	Wallowa Lake	ODFW files
	RB	25,137	4,740.00	7.2"	April, May, July				ODFW files
	LT	9,079	550.00	5.4"	June				ODFW files
1957	kokanee	78,200	26.00	0-2	04-26-57	Montana	Wallowa	Wallowa Lake	ODFW files
1957	kokanee	165,025	43.00	0-2	05-22-57	Montana	Wallowa	Wallowa Lake	ODFW files
1957	kokanee	173,890	43.00	0-2	05-24-57	Montana	Wallowa	Wallowa Lake	ODFW files
1957	kokanee	117,250		0-2	04-30-57	Montana	Wallowa	Wallowa Lake	ODFW files
1957	kokanee	130,413	32.00	0-2	05-23-57	Montana	Wallowa	Wallowa Lake	ODFW files
	RB	64,452	8,236.00	6.9"	April-September				ODFW files
	LT	2,424	165.00	5.5"	May				ODFW files
1958	kokanee	411,900	100.00	0-2	12-03-58		Wallowa	Wallowa Lake	ODFW files
1958	kokanee	495,000	100.00	0-2	05-01-58	Montana	Wallowa	Wallowa Lake	ODFW files
	LT	64,425	1,186.00	3.6"	May				ODFW files
	RB	41,152	8,660.00	8.1"	February				ODFW files
1959	RB	30,198	6,110.00	8.0"	April, June, July				ODFW files
	LT	65,788	1,300.00	3.7"	February				ODFW files
1960	kokanee	120,000	30.00	-1"	04-25-60	Montana	Wallowa	Wallowa Lake	ODFW files
1960	kokanee	120,000	30.00	-1"	04-28-60	Montana	Wallowa	Wallowa Lake	ODFW files
1960	kokanee	160,000	40.00	-1"	05-02-60	Montana	Wallowa	Wallowa Lake	ODFW files
1960	kokanee	120,000	30.00	-1"	04-26-60	Montana	Wallowa	Wallowa Lake	ODFW files
	LT	333,897	892.00	4.0"	April				ODFW files
	RB	40,006	9,363.00	8.5"	Apr, Jun, Jul, Aug				ODFW files
1961	kokanee	13,260	40.00	2"	08-29-61	Montana	Wallowa	Wallowa Lake	ODFW files
	LT	32,620	680.00	3.75"	March				ODFW files
	RB	29,631	9,137.00	9.2"	Apr, May, Jun, Aug				ODFW files
1962	kokanee	99,676	506.00	3"	06-20-62	Washington	Oak Spr	Wallowa Lake	ODFW files
1962	kokanee	1,530	25.50	3"	04-20-62	Montana	Wallowa	Wallowa Lake	ODFW files
	RB	27,228	8,747.00	9.4"	April-July				ODFW files
1963	kokanee	98,768	796.60	3"	06-13-63	Washington	Oak Spr	Wallowa Lake	ODFW files
1963	kokanee	61,325	207.80	2"	08-29-63	Washington	Fall River	Wallowa Lake	ODFW files
1963	kokanee	43,500	124.40	2"	08-14-63	Washington	Fall River	Wallowa Lake	ODFW files
	RB	36,020	10,786.00	9.1"					ODFW files
1964	kokanee	29,915	206.30	3"	05-14-64	B.C.	Wiz. Falls	Wallowa Lake	ODFW files
1964	kokanee	107,706	619.00	2"	05-05-64	B.C.	Wiz. Falls	Wallowa Lake	ODFW files
1964	kokanee	72,036	414.00	2"	05-05-64	B.C.	Wiz. Falls	Wallowa Lake	ODFW files
	RB	209,657	1,239.30	2.4"	May-August				ODFW files
1965	kokanee	79,780	534.00	2"	06-14-65	B.C.	Wiz. Falls	Wallowa Lake	ODFW files
1965	kokanee	63,151	424.00	3"	06-15-65	B.C.	Wiz. Falls	Wallowa Lake	ODFW files
1965	kokanee	61,960	443.00	3"	06-16-65	B.C.	Wiz. Falls	Wallowa Lake	ODFW files
1965	kokanee	51,352	358.00	2"	06-15-65	B.C.	Wiz. Falls	Wallowa Lake	ODFW files
	RB	34,395	10,102.00	9.1"	May-July, Dec				ODFW files
1966	kokanee	49,850	385.00	3"	06-21-66	B.C.	Oak Spr	Wallowa Lake	ODFW files
1966	kokanee	49,950	384.30	3"	06-17-66	B.C.	Oak Spr	Wallowa Lake	ODFW files
1966	kokanee	49,850	384.50	3"	06-15-66	B.C.	Oak Spr	Wallowa Lake	ODFW files
1966	kokanee	52,290	402.00	3"	06-23-66	B.C.	Oak Spr	Wallowa Lake	ODFW files
	RB	35,913	11,845.00	9.5"	May-July, Dec				ODFW files
1967	kokanee	49,769	465.00	3"	07-10-67	Montana	Oak Spr	Wallowa Lake	ODFW files
1967	kokanee	53,100	408.00	3"	07-10-67	Montana	Oak Spr	Wallowa Lake	ODFW files
	RB	33,129	10,830.00	9.5"	April-July				ODFW files
1968	kokanee	49,968	272.00	2"	07-01-68		Oak Spr	Wallowa Lake	ODFW files
	DV	1,897	21.80	3.0"	August				ODFW files

Year	Species	No.	Wt.	Size	Date	Origin	Hatchery	Area of Release	Reference
	RB	29,974	11,352.00	9.9"	Jan, Apr, Jul, Aug				ODFW files
1969	kokanee	50,600	595.00	3"	08-21-69		Oak Spr	Wallowa Lake	ODFW files
	RB	30,010	11,086.00	9.8"	Apr., Jun.-Aug.				ODFW files
1970	kokanee	50,215	797.00	3"	08-11-70		Oak Spr.	Wallowa Lake	ODFW files
	RB	30,082	11,263.00	9.6"	Apr., Jun.-Aug.				ODFW files
1971	RB	35,011	13,061.00	9.6"	Apr., Jun.-Aug.				ODFW files
1972	RB	35,003	14,627.00	10+"	April-August				ODFW files
1973	RB	34,482	13,061.00	9.9"	April-August				ODFW files
1974	RB	43,013	14,550.00	9.5"	July-August				ODFW files
	DV	19,500	130.00	2.5"	September				ODFW files
1975	RB	37,522	13,084.00	9.6"	April-August				ODFW files
	DV	5,009	255.00	6.0"	July				ODFW files
	DV	4,312	1,232.00	9.0"	October				ODFW files
	DV	13,089	395.00	4.2"	October				ODFW files
1976	RB	33,822	13,155.00	10.0"	April-August				ODFW files
	DV	7,304	1,660.00	8.6"	November				ODFW files
	DV	18,750	150.00	2.7"	November				ODFW files
1977	RB	42,544	16,237.00	9.9"	April-August				ODFW files
	DV	13,300	35.00	1.9"	July				ODFW files
	DV	5,000	1,250.00	8.6"	September				ODFW files
1978	RB	35,029	11,718.00	9.5"	April-August				ODFW files
	DV	6,560	800.00	6.8"	September				ODFW files
	DV	11,520	160.00	3.3"	?				ODFW files
1979	RB	39,036	13,395.00	9.6"	April-August				ODFW files
1980	RB	39,036	13,395.00	9.6"	April-August				ODFW files
1981	kokanee	31,978	271.00	2.4	07-16-81		WF	Wallowa Lake	ODFW files
	RB	28,004	9,775.00	9.6"	July-August				ODFW files
1982	kokanee	29,950	375.00	9.7"	08-06-82		WF	Wallowa Lake	ODFW files
	RB	44,008	155,562.00	3.1"	August				ODFW files
1983	RB	32,144	11,092.00	10+"	July-August				ODFW files
1984	RB	31,070	11,484.00	9.8"	July-August				ODFW files
1985	RB	30,506	9,583.00	9.3"	April-August				ODFW files
1986	RB	29,154	10,052.00	9.5"	April-August				ODFW files
1987	RB	16,117	5,640.00	9.6"	?				ODFW files
1988	RB	38,568	10,548.00	9.3"	?				ODFW files
1989	RB	32,547	10,684.00	9.4"	April-August				ODFW files

Appendix 9. Numbers of marked kokanee released in Wallowa Lake and recaptured by anglers (Table from 1975 annual Report, Wallowa District, ODFW).

	Kokanee release year (total number released in parentheses)						Hatchery K in Bag				
Harvest Year	1965 LP (265532)	1966 RV (202540)	1967 RP (100269)	1968 LV (50968)	1969 LP (51000)	1970 RV (50215)	Total	% of Total Catch	Total wild K in bag	Total K Catch	Mean Fk Length Spawning K
1967	12,500						12,500	69.4	5,500	18,000	8.56
1968	4,250	2,430					6,680	44.0	8,518	15,198	6.93
1969	295	4,970	231	30			5,526	30.0	12,897	18,423	7.15
1970		94	189	490			773	5.5	13,241	14,014	7.38
1971				166			166	2.4	6,729	6,895	7.5
1972			1,390	2,026	556	794	4,766	24.0	15,101	19,867	8.7
1973			1,204	1,444	1,685	1,926	6,259	31.2	13,809	20,068	9.34
1974			1,011	354	3,107	4,078	8,550	27.5	22,586	31,136	9.16
1975			95		181		276	1.6	17,001	17,277	7.9
	17,045	7,494	4,120	4,510	5,529	6,798	45,496		115,382	160,878	

Appendix 10 Time of spawning of coho at Grande Ronde and Wallowa River hatcheries. Data are number of females spawned.

Date	1901	1903	1906	1907	Date	1901	1903	1906	1907
10-Oct					09-Nov	26			2
11-Oct					10-Nov	14		71	
12-Oct					11-Nov	18	30		1
13-Oct					12-Nov	10			
14-Oct	8				13-Nov				
15-Oct	17				14-Nov	31			4
16-Oct	8	29			15-Nov	11			2
17-Oct	16				16-Nov	35			1
18-Oct	8				17-Nov				3
19-Oct	7	11		4	18-Nov	70	11		3
20-Oct	8			2	19-Nov	48			1
21-Oct	33				20-Nov				1
22-Oct	27	44		4	21-Nov	68			
23-Oct	18			4	22-Nov	30			
24-Oct	44	43		4	23-Nov				
25-Oct	37			2	24-Nov	151			1
26-Oct	41	49		3	25-Nov	154			
27-Oct	40		9		26-Nov	131			5
28-Oct	52			8	27-Nov	101			2
29-Oct	94	76	28	4	28-Nov	97			5
30-Oct	109	63	15	8	29-Nov				
31-Oct	70		16	9	30-Nov	88			
01-Nov	93		7	5	01-Dec				
02-Nov	56	34		4	02-Dec	137			
03-Nov	68			5	03-Dec	69			
04-Nov	94		20		04-Dec				
05-Nov	75	44	8	2	05-Dec				
06-Nov	92		9	2	06-Dec				
07-Nov	62	49	5	1	07-Dec				
08-Nov	26			3	08-Dec	19			
					Total females	2511	483	188	105
					Total eggs	7532300	1773000	527000	287300
					Eggs/female	3000	3671	2803	2736
						a,b	c		

Notes:
a. all spawnings were exactly 3000 eggs/female
b. Experimental rack also in Wenaha & egg take not differentiated
c. Wenaha River

Appendix 11. Natural coho production potential for Wallowa County streams.

STREAM NAME	TRIBUTARY OF	LWR BOUNDARY	UPR BOUNDARY	LENGTH (miles)	WIDTH (feet)	%USE BY COHO	USE TYPE	PARR/ SQ METER	PARR CAPACITY
WALLOWA R	GRANDE RONDE R	MOUTH	HOWARD CR	3.0	60	100%	2	0.023	2,031
WALLOWA R	GRANDE RONDE R	HOWARD CR	MINAM R	6.8	60	100%	2	0.023	4,603
WALLOWA R	GRANDE RONDE R	MINAM R	DEER CR	1.0	50	100%	2	0.023	564
WALLOWA R	GRANDE RONDE R	DEER CR	WATER CANYON	5.4	50	100%	2	0.023	3,046
WALLOWA R	GRANDE RONDE R	WATER CANYON	ROCK CR	1.4	50	100%	2	0.023	790
WALLOWA R	GRANDE RONDE R	ROCK CR	DRY CR	3.2	50	100%	2	0.023	1,805
WALLOWA R	GRANDE RONDE R	DRY CR	BEAR CR	0.4	50	100%	2	0.023	226
WALLOWA R	GRANDE RONDE R	BEAR CR	WHISKY CR	2.1	50	100%	2	0.023	1,185
WALLOWA R	GRANDE RONDE R	WHISKY CR	LOSTINE R	1.9	50	100%	2	0.023	1,072
WALLOWA R	GRANDE RONDE R	LOSTINE R	PARSNIP CR	3.2	50	100%	2	0.023	1,805
WALLOWA R	GRANDE RONDE R	PARSNIP CR	WADE GULCH	5.8	50	100%	2	0.023	3,272
WALLOWA R	GRANDE RONDE R	WADE GULCH	TROUT CR	6.7	50	100%	1	0.075	12,324
WALLOWA R	GRANDE RONDE R	TROUT CR	SPRING CR	0.3	50	100%	1	0.075	552
WALLOWA R	GRANDE RONDE R	SPRING CR	HURRICANE CR	0.1	50	100%	1	0.075	184
WALLOWA R	GRANDE RONDE R	HURRICANE CR	LITTLE HURRICANE CR	0.5	50	100%	1	0.075	920
WALLOWA R	GRANDE RONDE R	LITTLE HURRICANE CR	PRAIRIE CR	1.7	50	100%	1	0.075	3,127
WALLOWA R	GRANDE RONDE R	PRAIRIE CR	WALLOWA L	7.7	50	100%	1	0.15	28,328
								SUBTOTAL	**65,833**
WENAHA R	GRANDE RONDE R	MOUTH	CROOKED CR	6.7	40	100%	2	0.015	1,972
WENAHA R	GRANDE RONDE R	CROOKED CR	FAIRVIEW CR	3.5	40	100%	2	0.015	1,030
WENAHA R	GRANDE RONDE R	FAIRVIEW CR	CROSS CANYON	0.2	40	100%	2	0.015	59
WENAHA R	GRANDE RONDE R	CROSS CANYON	WELLER CR	2.4	40	100%	2	0.015	706
WENAHA R	GRANDE RONDE R	WELLER CR	BUTTE CR	2.0	40	100%	2	0.015	589
WENAHA R	GRANDE RONDE R	BUTTE CR	ROCK CR	2.0	40	100%	1	0.15	5,886
WENAHA R	GRANDE RONDE R	ROCK CR	SLICK EAR CR	3.3	40	100%	1	0.15	9,712
WENAHA R	GRANDE RONDE R	SLICK EAR CR	BEAVER CR	0.1	40	100%	1	0.15	294
WENAHA R	GRANDE RONDE R	BEAVER CR	WENAHA R, N FK	0.6	40	100%	1	0.15	1,766
WENAHA R, N FK	WENAHA R	MOUTH	HEADWATERS	14	20	5%	2	0.015	103
WENAHA R, S FK	WENAHA R	MOUTH	ELK CR	0.5	17	100%	1	0.226	942
WENAHA R, S FK	WENAHA R	ELK CR	JAUSSAUD CR	1.2	17	100%	1	0.226	2,262
WENAHA R, S FK	WENAHA R	JAUSSAUD CR	COUGAR CANYON	1.2	17	100%	1	0.226	2,262
WENAHA R, S FK	WENAHA R	COUGAR CANYON	TRAPPER CR	1.1	17	100%	1	0.226	2,073
WENAHA R, S FK	WENAHA R	TRAPPER CR	MILK CR	1.5	17	100%	1	0.226	2,827
WENAHA R, S FK	WENAHA R	MILK CR	HEADWATERS	6	8	10%	1	0.226	532
WELLER CR	WENAHA R	MOUTH	HEADWATERS	4	2	5%	2	0.023	5
BEAVER CR	WENAHA R	MOUTH	HEADWATERS	7.8	6	1%	2	0.023	5
BUTTE CR	WENAHA R	SQUAW CR	BUTTE CR, E FK	6.1	15	30%	2	0.023	310
CROOKED CR	WENAHA R	MOUTH	FIRST CR	4.8	20	100%	1	0.15	7,064
CROSS CANYON	WENAHA R	MOUTH	HEADWATERS	3	2	10%	2	0.023	7
ELK CR	WENAHA R, S FK	MOUTH	HEADWATERS	4	3	25%	1	0.226	333
FAIRVIEW CR	WENAHA R	MOUTH	HEADWATERS	2	3	10%	2	0.023	7
JAUSSAUD CR	WENAHA R, S FK	MOUTH	HEADWATERS	4.6	3	10%	2	0.023	16
MILK CR	WENAHA R, S FK	MOUTH	SHOOFLY CR	0.7	12	100%	1	0.15	618
ROCK CR	WENAHA R	MOUTH	HEADWATERS	4	4	10%	2	0.023	18
SLICK EAR CR	WENAHA R	MOUTH	HEADWATERS	4.5	4	5%	1	0.226	100
TRAPPER CR	WENAHA R, S FK	MOUTH	HEADWATERS	3	4	5%	1	0.226	67
								SUBTOTAL	**41,562**
MINAM R	WALLOWA R	MOUTH	SQUAW CR	2.6	8.5	100%	2	0.008	87
MINAM R	WALLOWA R	SQUAW CR	COUGAR CR	7	60	100%	2	0.008	1,648
MINAM R	WALLOWA R	COUGAR CR	TROUT CR	0.5	60	100%	2	0.008	118
MINAM R	WALLOWA R	TROUT CR	MURPHY CR	2.2	60	100%	2	0.008	518
MINAM R	WALLOWA R	MURPHY CR	LITTLE MINAM R	6.3	60	100%	2	0.008	1,483
MINAM R	WALLOWA R	LITTLE MINAM R	HORSE BASIN CR	2.5	60	100%	2	0.008	589
MINAM R	WALLOWA R	HORSE BASIN CR	HORSEHEAVEN CR	1.2	60	100%	2	0.008	283
MINAM R	WALLOWA R	HORSEHEAVEN CR	WALLOWA CR	3	60	100%	2	0.008	706
MINAM R	WALLOWA R	WALLOWA CR	CHAPARRAL CR	1.1	60	100%	1	0.226	7,317
MINAM R	WALLOWA R	CHAPARRAL CR	GARWOOD CR	2	60	100%	1	0.226	13,303
MINAM R	WALLOWA R	GARWOOD CR	THREEMILE CR	2.5	60	100%	1	0.226	16,629

STREAM NAME	TRIBUTARY OF	LWR BOUNDARY	UPR BOUNDARY	LENGTH (miles)	WIDTH (feet)	%USE BY COHO	USE TYPE	PARR/ SQ METER	PARR CAPACITY
MINAM R	WALLOWA R	THREEMILE CR	LITTLE POT CR	1.4	60	100%	1	0.226	9,312
MINAM R	WALLOWA R	LITTLE POT CR	N MINAM R	1	60	100%	1	0.226	6,652
MINAM R	WALLOWA R	N MINAM R	POT CR	2.2	50	100%	1	0.226	12,194
MINAM R	WALLOWA R	POT CR	POLE CR	0.1	50	100%	1	0.226	554
MINAM R	WALLOWA R	POLE CR	ROCK CR	1.8	50	100%	1	0.226	9,977
MINAM R	WALLOWA R	ROCK CR	CHINA CAP CR	1.1	50	100%	1	0.226	6,097
MINAM R	WALLOWA R	CHINA CAP CR	LAST CHANCE CR	0.8	50	100%	1	0.226	4,434
MINAM R	WALLOWA R	LAST CHANCE CR	ELK CR	2.9	50	100%	1	0.226	16,074
MINAM R	WALLOWA R	ELK CR	GRANITE GULCH	1.7	50	100%	2	0.023	959
MINAM R	WALLOWA R	GRANITE GULCH	WILD SHEEP CR	0.8	50	100%	2	0.023	451
MINAM R	WALLOWA R	WILD SHEEP CR	TRAIL CR	2.9	50	100%	2	0.023	1,636
CHAPARRAL CR	MINAM R	MOUTH	HEADWATERS	4	4	20%	2	0.023	36
CHINA CAP CR	MINAM R	MOUTH	HEADWATERS	3.8	4	10%	2	0.023	17
COUGAR CR	MINAM R	MOUTH	HEADWATERS	5	4	5%	2	0.008	4
ELK CR	MINAM R	MOUTH	ELK CR, E FK	1.5	3	50%	2	0.015	17
GARWOOD CR	MINAM R	MOUTH	HEADWATERS	2.5	4	10%	2	0.008	4
LITTLE POT CR	MINAM R	MOUTH	HEADWATERS	3.2	4	10%	2	0.015	9
MURPHY CR	MINAM R	MOUTH	HEADWATERS	8.7	5	50%	2	0.015	160
POT CR	MINAM R	MOUTH	HEADWATERS	2.5	3	40%	2	0.015	22
SQUAW CR	MINAM R	MOUTH	HEADWATERS	10.2	4	10%	2	0.015	30
TROUT CR	MINAM R	MOUTH	HEADWATERS	11.4	4	10%	2	0.015	34
WALLOWA CR	MINAM R	MOUTH	HEADWATERS	3.5	4	5%	2	0.015	5
WILD SHEEP CR	MINAM R	MOUTH	HEADWATERS	3.5	3	5%	2	0.015	4
								SUBTOTAL	**111,363**
DEER CR	WALLOWA R	MOUTH	SAGE CR	11.9	10	100%	1	0.075	4,378
DEER CR	WALLOWA R	SAGE CR	HEADWATERS	7.9	10	10%	2	0.008	31
								SUBTOTAL	**4,409**
BEAR CR	WALLOWA R	MOUTH	LITTLE BEAR CR	8.1	25	100%	2	0.008	795
BEAR CR	WALLOWA R	LITTLE BEAR CR	DOC CR	1.4	25	100%	1	0.075	1,288
BEAR CR	WALLOWA R	DOC CR	GOAT CR	4.3	25	100%	1	0.15	7,910
BEAR CR	WALLOWA R	GOAT CR	HEADWATERS	10.6	20	10%	1	0.15	1,560
GOAT CR	BEAR CR	MOUTH	HEADWATERS	6.4	8	1%	2	0.008	2
LITTLE BEAR CR	BEAR CR	MOUTH	HEADWATERS	8.2	10	50%	2	0.015	302
								SUBTOTAL	**11,856**
LOSTINE R	WALLOWA R	MOUTH	SILVER CR	14.2	30	100%	1	0.15	31,344
LOSTINE R	WALLOWA R	SILVER CR	LAKE CR	4.6	30	100%	1	0.075	5,077
LOSTINE R	WALLOWA R	LAKE CR	E LOSTINE R	7.1	30	100%	1	0.15	15,672
								SUBTOTAL	**52,094**
SPRING CR	WALLOWA R	MOUTH	HEADWATERS	2.5	8	100%	1	0.15	1,472
SPRING CR, S FK	SPRING CR	MOUTH	HEADWATERS	6	2	100%	1	0.15	883
								SUBTOTAL	**2,355**
HURRICANE CR	WALLOWA R	MOUTH	HEADWATERS	20.4	20	5%	1	0.075	751
LITTLE HURRICANE CR	WALLOWA R	MOUTH	HEADWATERS	3.5	7	10%	1	0.15	180
								SUBTOTAL	**931**
PARSNIP CR	WALLOWA R	MOUTH	UNNAMED	4	5	5%	1	0.15	74
								SUBTOTAL	**74**
PRAIRIE CR	WALLOWA R	MOUTH	OK GULCH	7	15	100%	2	0.015	773
PRAIRIE CR	WALLOWA R	OK GULCH	PRAIRIE CR, W FK	6.8	8	50%	1	0.075	1,001
								SUBTOTAL	**1,773**
								GRAND TOTAL	**291,362**